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Tredgold

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THE PRINCIPLES AND PRACTICE

OF THE CONSTRUCTION

OF STEAM ENGINES

IN

STATIONARY AND MARINE ENGINES

EXAMPLES

OF

STEAM NAVIGATION, AND OF THOSE EMPLOYED

IN HER MAJESTY'S SERVICE

WITH AN EXAMPLE OF THE TURBINE WHEEL

INCLUDING ALSO

A DESCRIPTION OF THE LATEST IMPROVED METHOD OF

THE LATE MR. TREDGOLD'S WORK

AS APPLIED TO MARINE ENGINES AND BOILERS WITH EXPLANATIONS
OF THE PRINCIPLES

AND A GENERAL INDEX

VOL. III

JOHN WEALE 25, HIGH HOLBORN

PRINTED BY

THE PRINCIPLES AND PRACTICE
AND
EXPLANATION OF THE CONSTRUCTION
OF
THE STEAM ENGINE,
INCLUDING
PUMPING, STATIONARY, AND MARINE ENGINES:
EXAMPLES
OF
BOILERS USED FOR STEAM NAVIGATION, AND OF THOSE EMPLOYED
IN HER MAJESTY'S SERVICE;
TOGETHER WITH AN EXAMPLE OF THE TURBINE WHEEL:
INCLUDING ALSO
THE NEW SUBJECTS CONTAINED IN THE PRESENT AMENDED EDITION OF
THE LATE MR. TREDGOLD'S WORK,
A GLOSSARY OF TERMS APPLICABLE TO MARINE ENGINES AND BOILERS, WITH FRENCH AND
SPANISH TRANSLATIONS,
AND A GENERAL INDEX.

VOL. III.

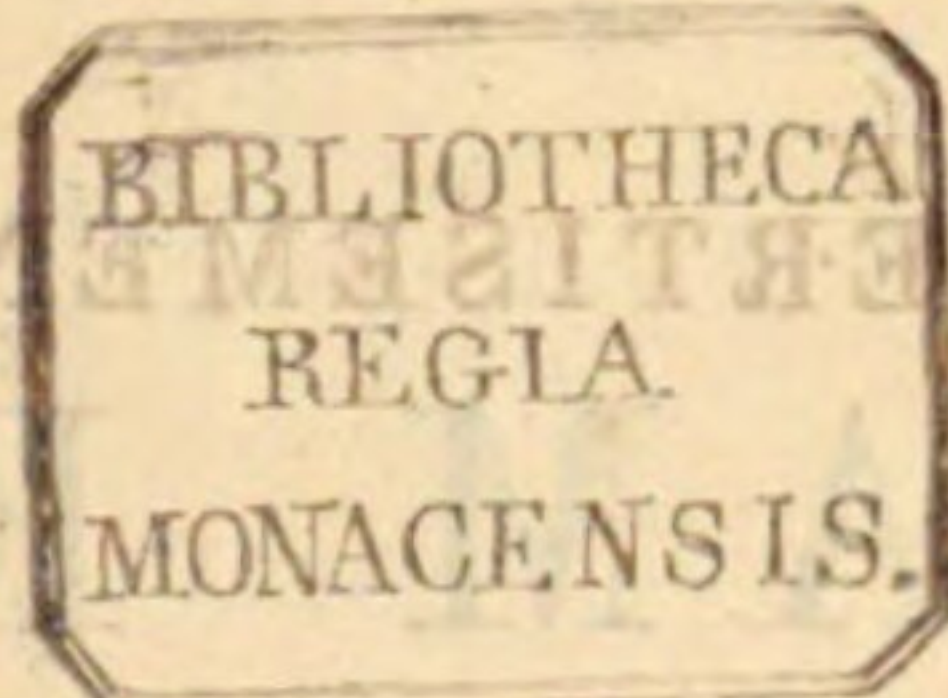
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THE PRINCIPLES AND PRACTICE

EXPLANATION OF THE CONSTRUCTION



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HUGHES, PRINTER,
KING'S HEAD COURT, GOUGH SQUARE.

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The plates will be found to exist in the numbering of the Plates, and
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For the unavoidable procrastination of its completion, which has resulted from the almost incessant occupation of those Gentlemen who have so kindly contributed to its perfection, he solicits the indulgence of the Subscribers.

Some discrepancies will be found to exist in the numbering of the Plates, but these have been principally caused by the substitution of Modern Examples for those of an earlier date, and by a desire on the part of the Contributors of New Subjects that their drawings should be designated by numbers independent of those contained in the preceding edition. A reference to the List of Plates prefixed to each volume will remove any apparent difficulty on this point, and the Summary of Engravings will show that the work is illustrated by a greater number of Plates than were promised in the Prospectus.

The present volume contains some elaborate investigations on the merits of the Paddle-Wheel and the Screw as Propellers of Steam Vessels, with Experiments by GEORGE RENNIE, Esq. on the advantages of the trapezium or triangular Floats

over those of a rectangular shape; also an Investigation of the Resistance to the Blades of the Screw Propeller, by Mr. R. BODMER; and to these are added a series of Experiments on the Paddles of Steamers—their figure, dip, thickness, material, number, &c., by Mr. EWBANK, of New York.

The Practical Essay on Marine Boilers, by Mr. JOHN DINNEN, R.N., with Notes by Mr. ROBERT ARMSTRONG, will be found to contain much valuable information on “a subject of great national importance, and which has assumed a prominent feature in Her Majesty’s Naval Service.”

A ‘Glossary of Terms connected with Marine Engines and Boilers, with French and Spanish Translations,’ kindly contributed by Captain QUESADA, of the Royal Spanish Navy, and a GENERAL INDEX, complete the work, which is now respectfully submitted to the approbation of the Subscribers and of the Public.

J. W.

November 1, 1852.

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VOL. II. is bound in two volumes for convenience of size, thus making four volumes in the binding.

DIVISION C.—STATIONARY ENGINES.

FIRST PAPER.

PUMPING ENGINE ERECTED AT THE NEW DRY DOCK FOR THE NAVAL STATION, NEW YORK.

THE Pumping Engine of the new Dry (or Graving) Dock at the United States' Naval Station, New York, is of the largest class, and possesses many interesting features. It was built at Kemble's West Point Foundry, and affords additional proof of the capability of that establishment to execute the most massive work in the highest degree of perfection.

There are but very few specimens of large pumping engines to be found in the United States, those of the Government dry docks at Norfolk and Boston being the most important. These, however, are of somewhat antiquated construction, and possess no remarkable qualities of excellence. The new dock at New York being the largest in the country, and at the most extensive naval station, it was deemed important that the machinery for exhausting it should be of the most perfect kind, and of great power and capacity also, as but a very inconsiderable amount of aid is afforded by the recession of the tide.

A Commission was therefore constituted by the Bureau of Yards and Docks, consisting of W. J. McAlpine, Esq., Chief Engineer of the Dock, Charles W. Copeland, Esq., Naval Constructing Engineer, and William M. Ellis, Esq., Engineer of the Washington Navy Yard, whose duty it should be to devise and perfect the plans for the work.

The 'duty' required of the engine was to raise 610,000 cubic feet of sea water in three hours, distributed through different heights, as follows:

110,000	cubic feet of water raised through an average height of	2½ feet.
125,000	„ „	7½ „
115,000	„ „	12½ „
110,000	„ „	17½ „
110,000	„ „	22½ „
40,000	„ „	26 „
610,000		

The Commission unanimously adopted the plan shown in the accompanying drawings, a brief description of which is here given.

The Pumps are two in number, of the kind denominated 'lifting-pumps,' each 63 inches in diameter of cylinder and 8 feet length of stroke. The suction-pipes (also 63 inches in diameter) are extended to the bottom of the well, and terminate in suitable rose-pieces, with ample apertures in the sides for the admission of the water. By this arrangement a staunch support is furnished for the insistent weight of the upper works of the pumps and the engine above. Each suction-pipe is furnished with a capacious branch-piece (63 inches diameter), forming a connection with an air (or vacuum) chamber, situated centrally between the pumps, and extending up to the bottom of the upper (or engine) bed-plate. This air-chamber, in addition to the support received from the branch-pipes, is upheld by a hollow cylindrical pillar resting on the bottom of the well. A continuation of this pillar is carried through the centre of the air-chamber to the under side of the lower (or pump) bed-plate.

The pump-cylinders, suction and branch pipes, the air-chamber and its support, are of cast iron, flanged and ribbed as shown in the drawings, the pump-cylinders being lined with composition metal.

The mouths of the pumps are placed at the level of mean low water, in a chamber formed of cast iron, 8 feet wide, 13 feet high, and 30 feet long,—the bottom of the chamber forming a support to the heads of the pump-cylinders, as well as a bed-plate for the air-pump and condenser of the engine: its sides, strongly ribbed, support the engine bed-plate with the superstructure, and the top is itself a part of the engine bed-plate. A culvert from the bay leads up to one of the sides of this chamber, and serves as a conduit for the water delivered from the pumps. Twelve of the panels of the side of the chamber adjoining the conduit are open, and furnished with flap-valves of vulcanized India-rubber, opening outwardly to prevent the rising tide from flowing into the chamber. Four cast-iron girders of $\mathbf{I}$ section, 32 inches deep, are placed transversely across the well, directly underneath the bottom of this chamber, and are held down to the masonry by suitable bolts.

The arrangement of the pump-valves is of somewhat novel character, a suction-valve being placed near the bottom of each suction-pipe, in addition to the usual one near the bottom of the pump-chambers. Each of these valves is provided with suitable chests and bonnets, and is composed of vulcanized India-rubber, with the usual metal guard above. A disc of India-rubber, cut to the proper shape, with punctures along its diameter, is slipped over standards, tapped into the valve-seat, and secured by washers and the nuts of the guard; the India-rubber alone, from its flexibility, forming the hinge.

The valve-seats are of composition metal, their faces being indented in such a manner as to require two sets of valves to each chest, and are divided into

numerous apertures by narrow but deep bars, crossing each other at right angles. This cross-barring forms a support for the flexible material of the valve, and obviates all the difficulty to be apprehended from the tendency of the valve to collapse on being loaded. A perfectly tight and quiet-working valve is the consequence of this arrangement.

The pump-rods are double, and, passing through stuffing-boxes in the floating covers with which the pumps are provided, take hold of cross-heads working in slides below the engine bed-plate. From these cross-heads, double connecting-rods extend directly to the beam of the engine. The pumps are placed 21 feet apart from centre to centre; the working beam is 31 feet in length.

The whole of this pump-work is placed in an oval well, 30 by 20 feet, the bottom of which is 28 feet below the level of mean low water. The masonry of the well is of the most substantial character, massive, and adequately buttressed.

The Engine is a double-acting condensing one, of 50 inches diameter of cylinder and 12 feet length of stroke, with an independent adjustable expansion-gear, so arranged, that as the load upon the engine is increased by the lowering of the water in the dock, a proportionate increased amount of steam is admitted into the cylinder. This is effected by a simple arrangement, consisting of a cam-wheel on the balance-wheel shaft, against which a cam-roller, suitably connected with the expansion-valve stems, is made to revolve, and along which it can be made to travel at any rate of speed desired. The whole is rendered capable of adjustment by hand, or it can be thrown out entirely.

The working beam is of cast iron, 31 feet long between the 'end centres,' and 4 feet deep at the 'main centre,' strongly flanged and bossed. The piston-rod is attached to the beam by a parallel motion; the main-pump and air-pump rods are connected to it by double rods and links, the air-pump cross-head working in slides attached to the columns of the engine-frame. The rod connecting the balance-wheel crank with the beam is trussed by tie-rods joined to each end of the rod and to each other by suitable bolts, and passing over a straining strut at the centre, with provision for tightening the whole by screws and nuts. The balance-wheel is of cast iron, 25 feet in diameter, a cross-section of its rim having an area of about 80 square inches. Its arms (eight in number) unite in a centre case, having compartments to receive their tapered ends. The shaft and crank are of wrought iron.

The framing of the engine is of cast iron, and consists of an entablature supported on double lines of Gothic arches and columns, ending against the walls of the engine-room. Side arches, surmounted by an entablature, are thrown from the centre of the main to the sides of the room. The whole rests upon the bed-plate before described and upon a granite pediment continued to the ends

of the apartment: a cast-iron flooring, figured in relief, surrounds the whole. The drawings show the style of ornament that has been given to the whole work, care having been taken to have all the parts in keeping with each other.

The condenser is formed from a portion of the air or vacuum chamber before described, a partition being placed in that portion of it which extends above the engine bed-plate.

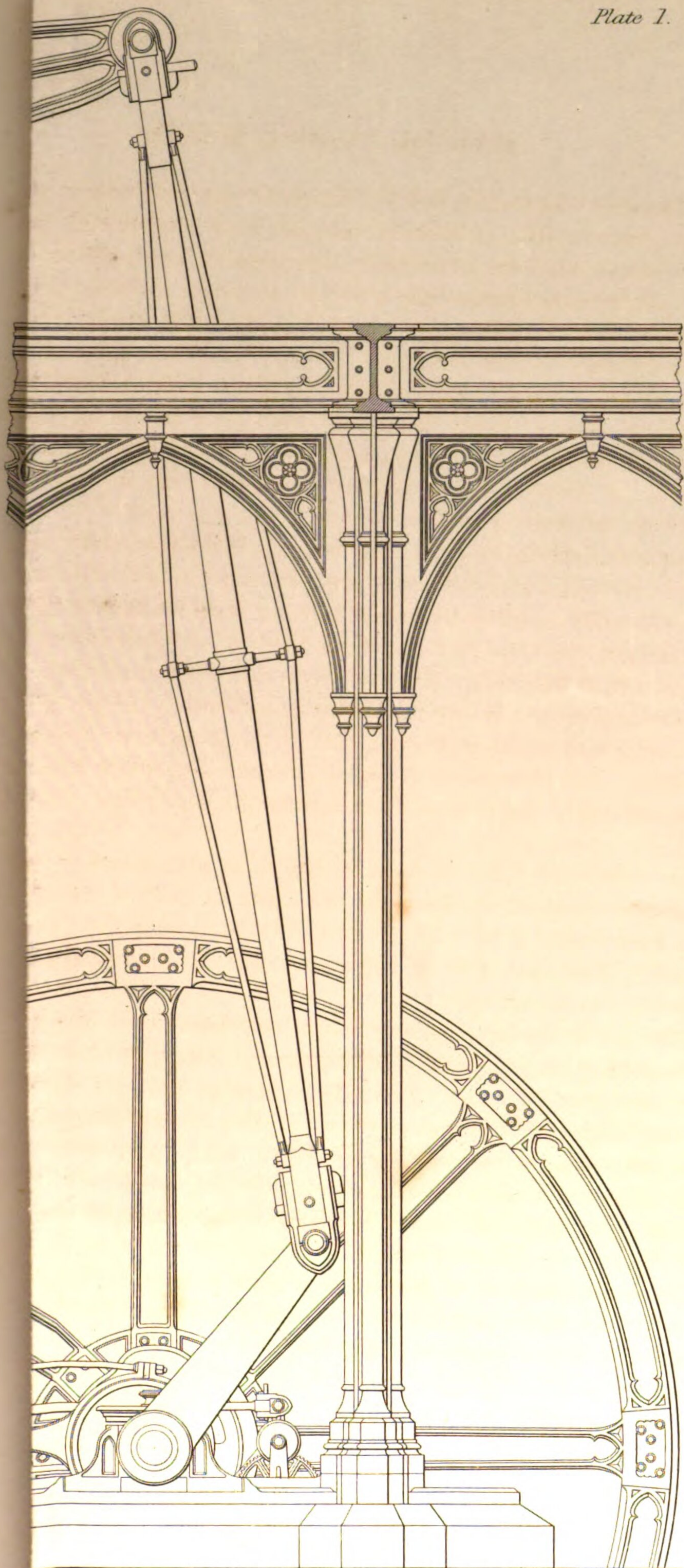
The air-pump stands level with the condenser, is fitted with a floating cover, and sustains upon its upper flange the usual reservoir. The air-pump rod and bucket, foot-valve and seat, are of composition metal. The length of stroke is 42 inches, the diameter of the cylinder 44 inches. The interior of the cylinder is lined with composition metal.

The piston, cylinder-cover, and steam-chests, side-pipes, valves, and valve-gearing with their eccentrics and rock-shaft, are all nearly identical with those used in the best specimens of *American steam-boat engines*; accurate and detailed drawings and descriptions of which will be found under the head of 'American Marine Engines,' in Division B. of this work. The side-pipes, rock-shaft and stand, and all wrought-iron moving parts of the engine, are highly polished. The cylinder is felted and covered with a casing of mahogany, and all the journals are fitted with automaton oil-feeders. The front of the engine is mounted with steam and vacuum gauges and an indicator, and also with a register for numbering the strokes of the pumps.

The boilers are three in number, situate in a fire-proof room adjoining the engine, where careful arrangements are made to prevent radiation. They are 26 feet long, and of 7 feet diameter in the waist, built on the 'single return drop flue' plan. The flues of all the boilers discharge into a transverse one underneath, connecting with the chimney.

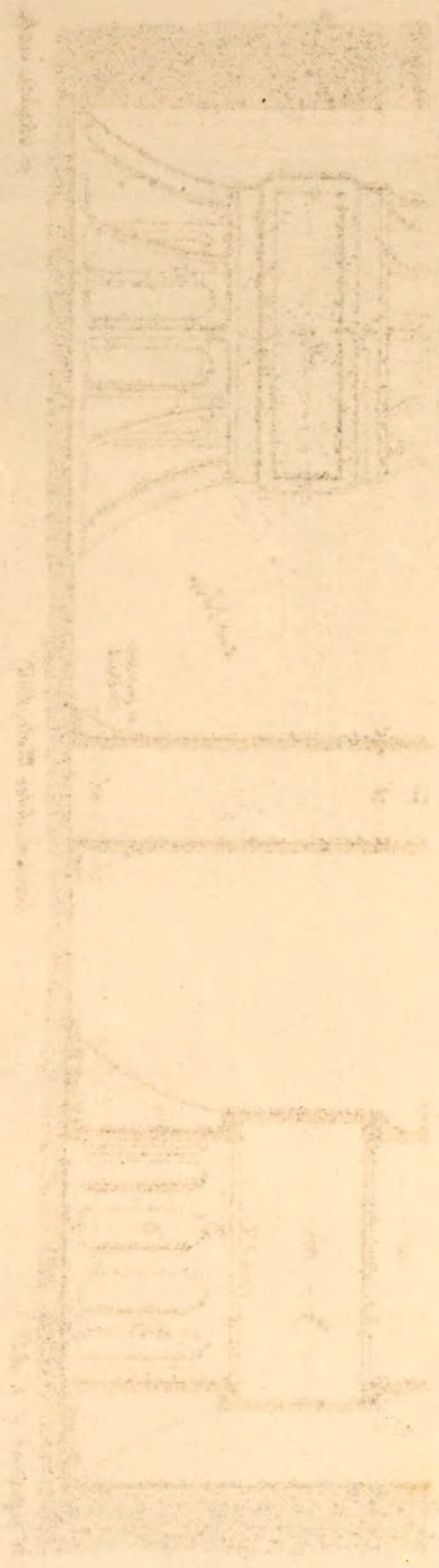
There are no feed-pumps attached to the engine, the boilers being fed by the direct-action steam-pumps of Worthington and Baker, of New York, each boiler having one attached to it. This steam-pump is now very extensively used for supplying boilers, and for a great variety of other kinds of pumping. The driving-engine and pump are both on the same frame, and have the same piston-rod. The steam-valves are actuated by an arm from the piston-rod working against tappets upon the valve-stem. A beautifully ingenious and simple device insures the valve being thrown with unerring certainty, without the aid of springs or weights.

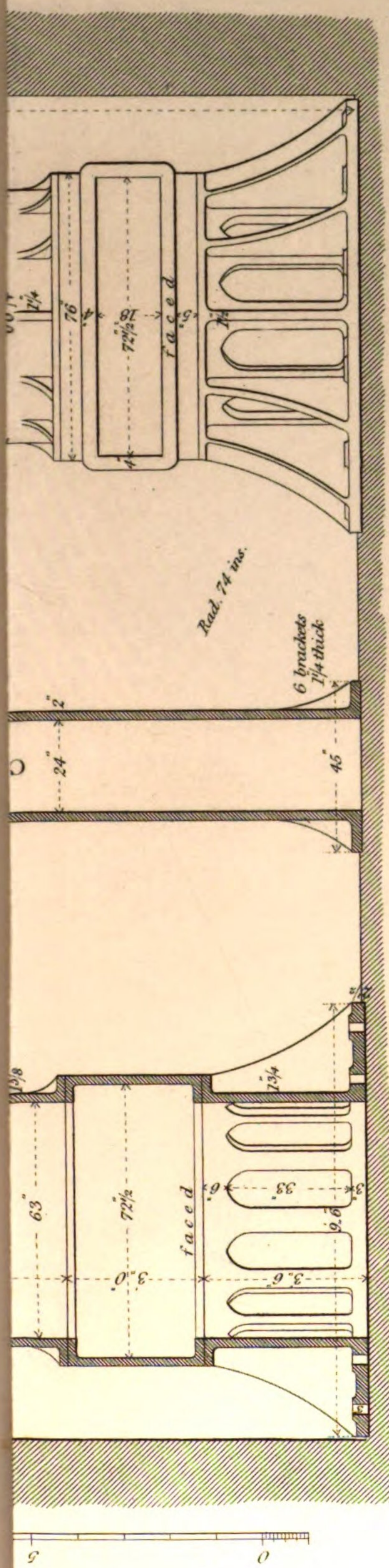
The engine-house is of granite, of a plain exterior finish, and the apartment devoted to the engine is fitted up in a style to correspond with the design of the engine: it is 60 feet square and 50 in height.

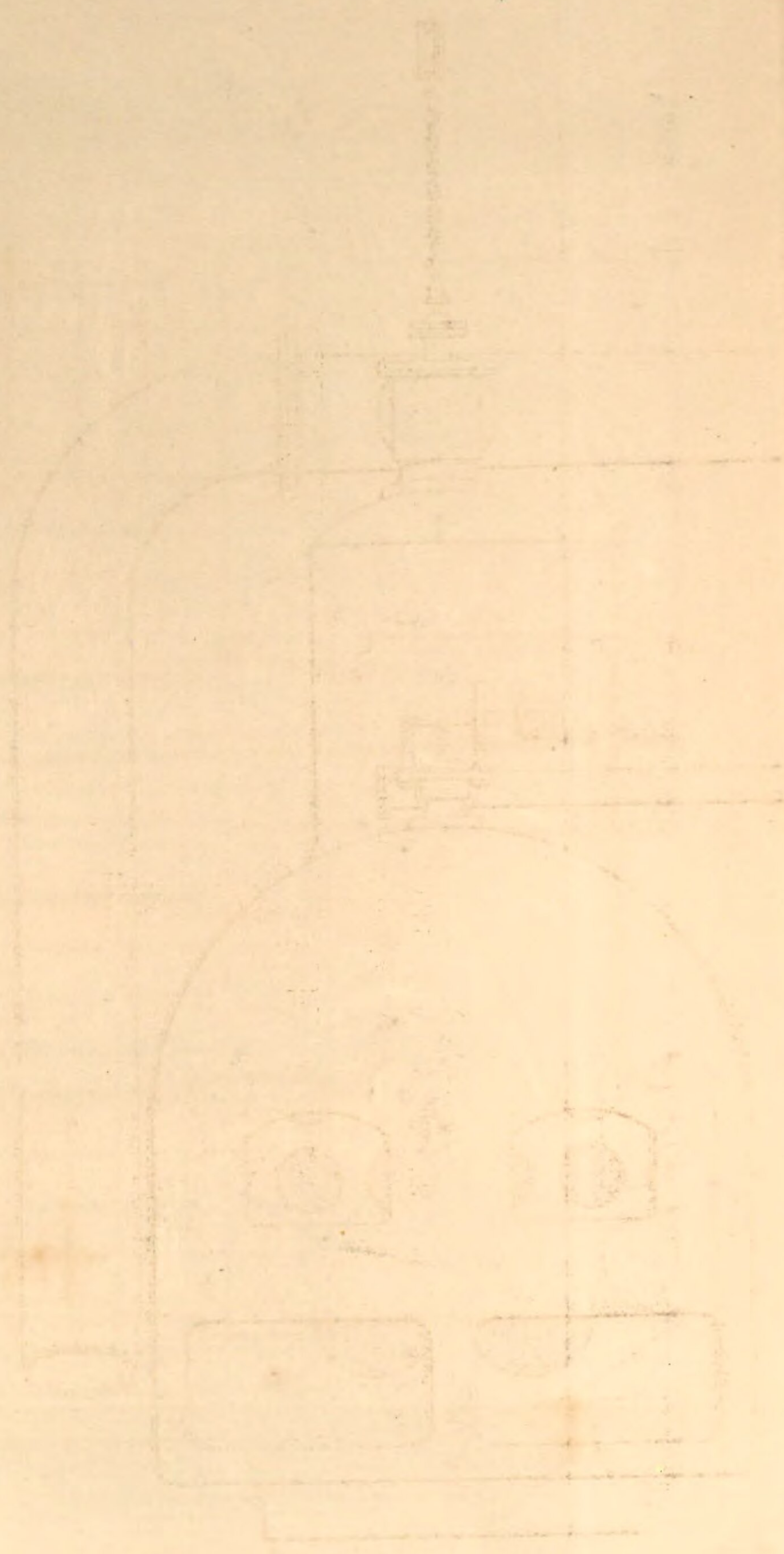


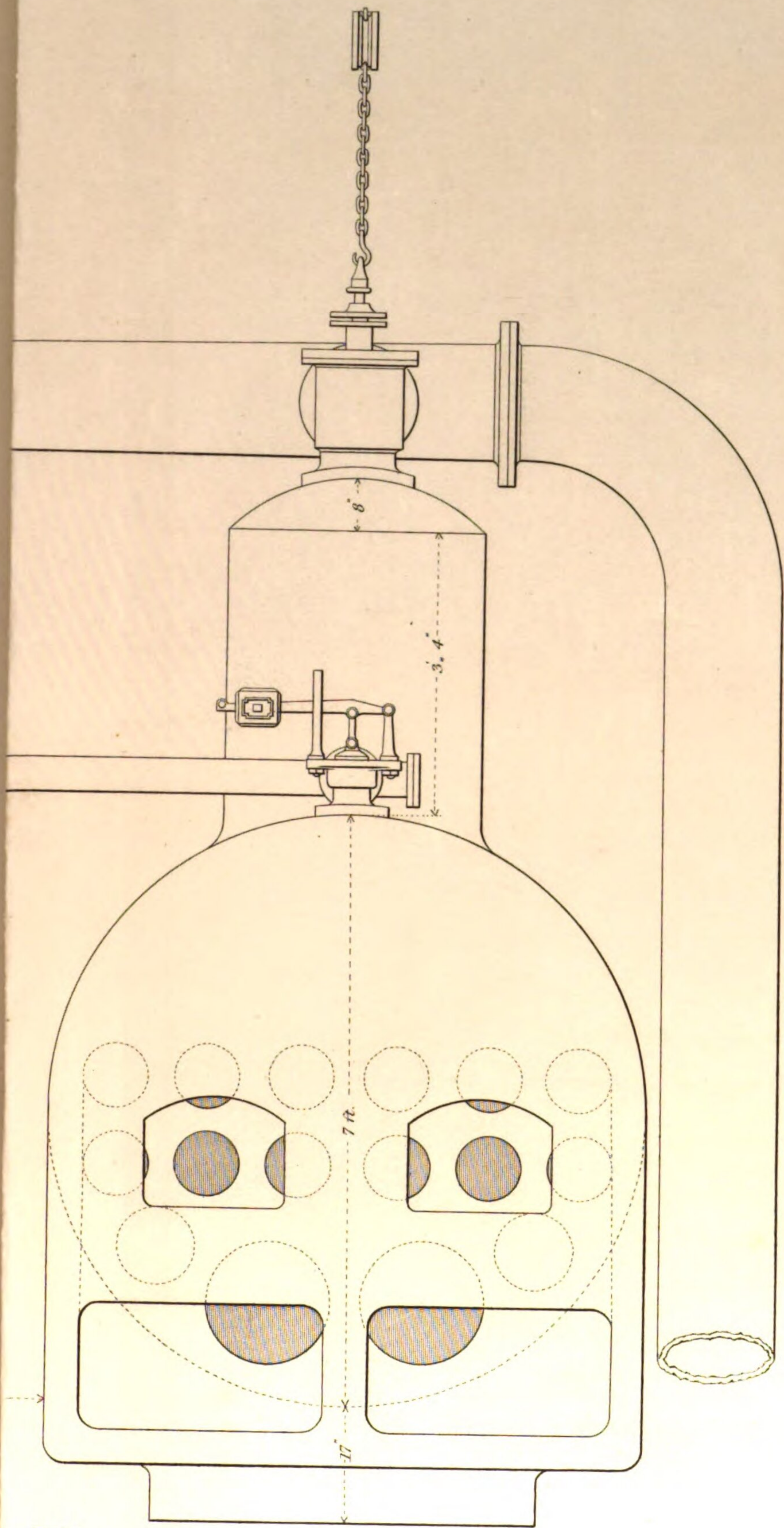
25 feet

G. Gladwin, sculp.





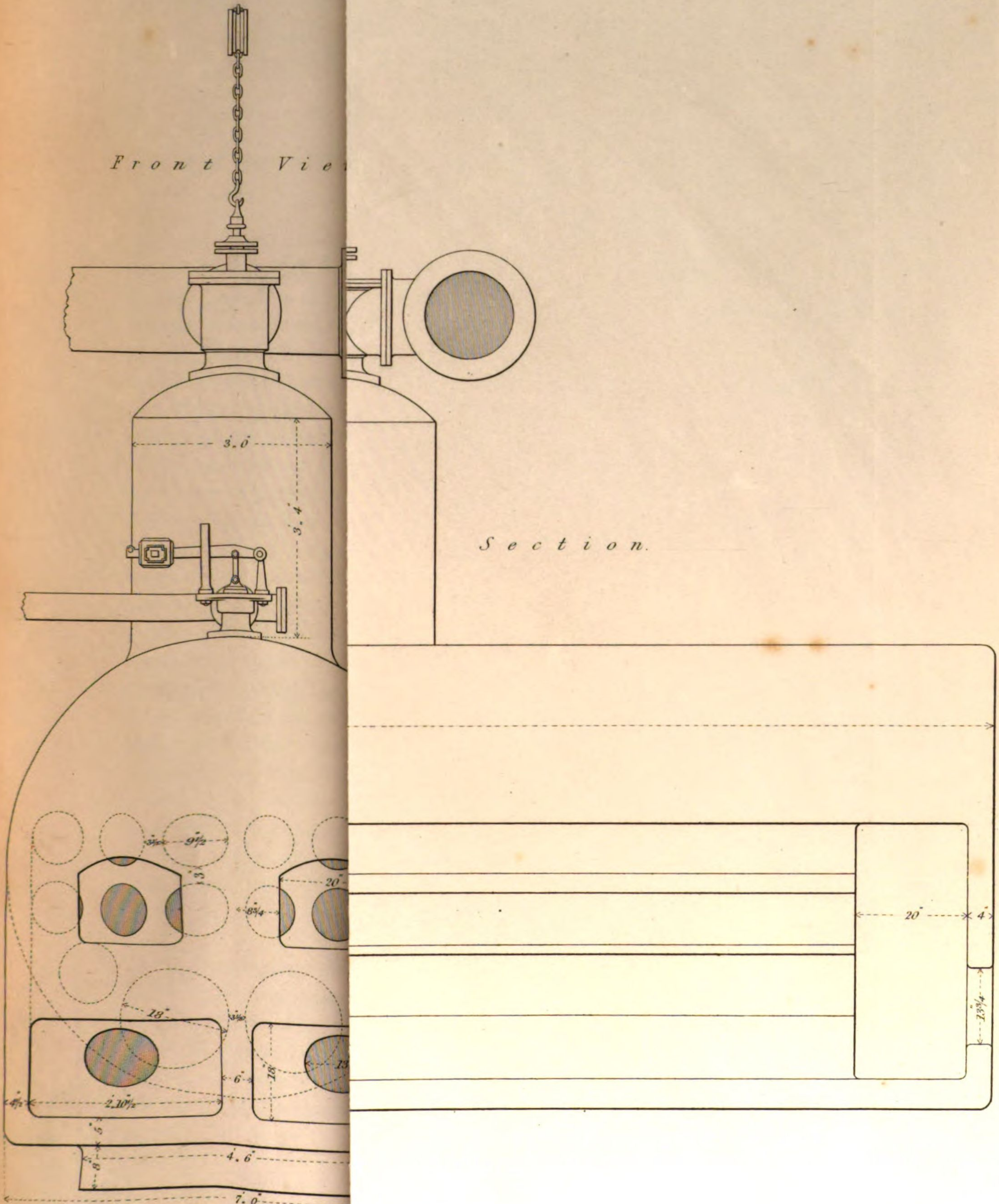






Front View

Section.



C. W. Copeland, N. Y. del^t

G. Gladwin, sculp.

DIVISION C.—STATIONARY ENGINES.

SECOND PAPER.

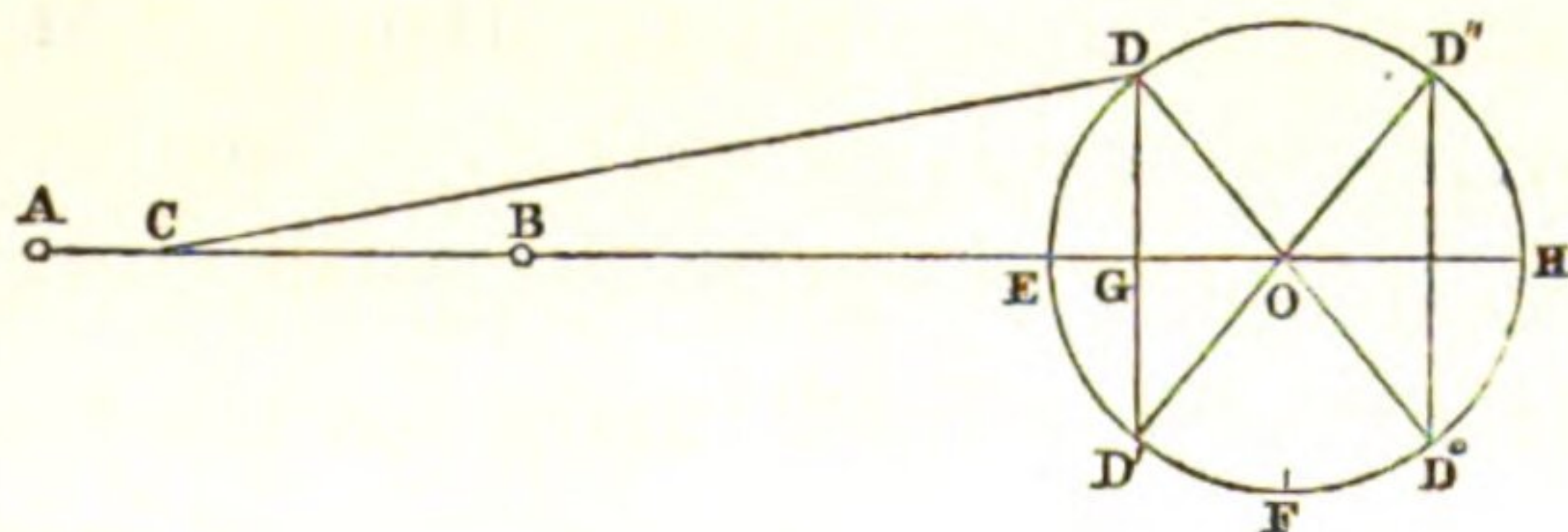
ON THE GENERAL THEORY OF THE STEAM ENGINE.

BY W. S. B. WOOLHOUSE, ESQ., M. R. A. S., &c.

THE mechanical relations of the steam engine, or the principles upon which the power is transmitted from the cylinder, are of a simple and elementary nature. To discuss them it is only necessary to have recourse to the properties of the crank and the well-understood mechanical powers, the lever, the wheel and axle, and the inclined plane. In every combination of the ordinary mechanical powers, supposed to be divested of friction, the transmission of force follows the well-known law, that the efficient power is of precisely the same value at each point, understanding the efficient power to be the force of resistance multiplied into the velocity. Thus the effect produced, or the effective power, is measured by the weight moved, or resistance overcome, multiplied by its velocity: the moving power is similarly measured by its force multiplied by its velocity; and these powers would in all cases be equal, were it not for the effects of friction. To preserve distinctness, we shall designate the pressure by the term *pressure* or *force*, and the effect produced, or the force multiplied into the velocity, by the term *power*; the former of these may likewise be called the *statical*, and the latter the *dynamical* value of the force. These terms being agreed upon, it follows that in every machine composed of the ordinary mechanical powers, the quantity of power developed, or the dynamical effect of the force, would be the same at all points; that the power, by such arrangement, is transmitted without any change in its value, except it be such as is caused by the loss resulting from friction. It would be easy to show that this principle is universal, or, in other words, that it applies to every possible combination of machinery; but this is quite unnecessary for our present object, though it may perhaps not be out of place to make a few observations on the nature of the crank, in addition to what has been stated in the present work.—See article ‘Crank.’

I.—ACTION OF THE CRANK.

In the annexed figure let $CD = r$ be the length of the connecting rod; $OD = \rho$ the radius of the crank; the angle (DOE) described $= \alpha$; the velocity at $C = v$; the velocity of $D = v'$, and the distance (AC) described $= x$. Then,



the perpendicular $DG = \rho \sin. \alpha$; $CG = \sqrt{r^2 - \rho^2 \sin.^2 \alpha}$; $OG = \rho \cos. \alpha$; $CO = \sqrt{r^2 - \rho^2 \sin.^2 \alpha} + \rho \cos. \alpha$; $AO = r + \rho$; and therefore the value of AC , or $AO - CO$, is

$$\begin{aligned} x &= r + \rho - (\sqrt{r^2 - \rho^2 \sin.^2 \alpha} + \rho \cos. \alpha) \\ &= \rho (1 - \cos. \alpha) + (r - \sqrt{r^2 - \rho^2 \sin.^2 \alpha}) \dots (1). \end{aligned}$$

By differentiating this expression of the distance traversed by C , we obtain the velocity of the extremity C , viz.:

$$\begin{aligned} \frac{dx}{dt} &= \frac{\rho d\alpha}{dt} \sin. \alpha \left(\frac{\rho \cos. \alpha}{\sqrt{r^2 - \rho^2 \sin.^2 \alpha}} + 1 \right); \text{ that is,} \\ v &= v' \sin. \alpha \left(\frac{\rho \cos. \alpha}{\sqrt{r^2 - \rho^2 \sin.^2 \alpha}} + 1 \right) \dots (2). \end{aligned}$$

But if P denote the moving force acting at C , in the direction CB , P' the effective force of D , and $r = n\rho$, it has been shown in the article on 'Crank,' by means of the resolution of the forces, that $P' = P \sin. \alpha \left(\frac{\cos. \alpha}{\sqrt{n^2 - \sin.^2 \alpha}} + 1 \right)$, or, replacing n by $\frac{r}{\rho}$,

$$P' = P \sin. \alpha \left(\frac{\rho \cos. \alpha}{\sqrt{r^2 - \rho^2 \sin.^2 \alpha}} + 1 \right) \dots (3).$$

Equation (2) hence reduces to $v = v' \frac{P'}{P}$, and therefore

$$Pv = P'v' \dots (4);$$

that is, the moving *power* at C is always equal to the effective power at D .

The moving force P being nearly uniform, the force P' expressed by the equation (3) will be materially different at different positions of the crank, and the velocity of the engine will, in consequence, be subject to small fluctuations in the course of each revolution. To ascertain the law of these variations, it will be necessary to have recourse to the usual equation of rotatory motion. Let R denote the real moment of the resistance, including friction, reduced to the point D , or the force which uniformly applied along the circumference ED would just suffice to preserve the mean velocity of the engine without any variation. Then P' being the force actually applied, the effective accelerating force, or the part tending to produce acceleration, will be $P' - R$; and where this is negative, the velocity $\frac{d\alpha}{dt}$ must be retarded instead of accelerated. If we now multiply the force $P' - R$ by ρ , the leverage at which it acts, the product $\rho(P' - R)$ is its moment or tendency to generate angular motion. Hence, if M designate the moment of the inertia to be overcome, and if we neglect, as comparatively insignificant, the slight variations of the resistance R due to the small changes of velocity, and suppose it to continue uniform, we shall have

$$M \frac{d^2 \alpha}{dt^2} = \rho(P' - R).$$

Multiply by $\frac{2 d \alpha}{d t}$, and

$$\begin{aligned} M \frac{2 d \alpha d^2 \alpha}{d t^3} &= 2 P' \rho \frac{d \alpha}{d t} - 2 R \rho \frac{d \alpha}{d t} \\ &= 2 P' v' - 2 R \rho \frac{d \alpha}{d t} \\ &= 2 P v - 2 R \rho \frac{d \alpha}{d t} \\ &= 2 P \frac{d x}{d t} - 2 R \rho \frac{d \alpha}{d t}. \end{aligned}$$

Consequently, by integration,

$$\begin{aligned} M \left(\frac{d \alpha}{d t} \right)^2 &= 2 (P c + P x - R \rho \alpha) \\ \therefore \frac{d \alpha}{d t} &= \sqrt{\frac{2}{M} (P c + P x - R \rho \alpha)} \dots (5). \end{aligned}$$

Now, the engine being supposed to have acquired her permanent speed, there can be no progressive acceleration; the same velocity must recur at the period of each revolution. The velocity at E is obtained by putting $x = 0$, $\alpha = 0$, and is

$$\left(\frac{d \alpha}{d t} \right)' = \sqrt{\frac{2}{M} P c} \dots (a).$$

Also, the velocity at H is obtained by putting $x = 2 \rho$, $\alpha = \pi (= 3.14159)$, and is

$$\left(\frac{d \alpha}{d t} \right)'' = \sqrt{\frac{2}{M} (P c + 2 P \rho - R \rho \pi)} \dots (b).$$

Again, it is to be observed that the preceding investigation equally applies to the returning motion along $H D^\circ$, provided, in that case, the symbol α represents the angle $H O D^\circ$, and x' , which is accentuated for distinction, the retrograde distance B C. If therefore, $\alpha x'$ being each nought, the velocity at H be

$$\left(\frac{d \alpha}{d t} \right)'' = \sqrt{\frac{2}{M} P c'} \dots (c),$$

when $\alpha = \pi$, $x' = 2 \rho$, the recurring velocity at E will be

$$\left(\frac{d \alpha}{d t} \right)''' = \sqrt{\frac{2}{M} (P c' + 2 P \rho - R \rho \pi)} \dots (d).$$

Thus it appears that the squares of the three velocities $\left(\frac{d \alpha}{d t} \right)' \left(\frac{d \alpha}{d t} \right)'' \left(\frac{d \alpha}{d t} \right)'''$ are in arithmetical progression, and that this progression would go on indefinitely if the resistance R did not augment so as to destroy the common difference $2 P \rho - R \rho \pi$, and cause the same velocity to recur at each period. It hence follows, that so long as the smallness of R renders $2 P \rho - R \rho \pi$, or $2 P - R \pi$, positive, the engine will be acquiring additional speed; and that when R becomes such that $2 P - R \pi = 0$, the power will just be capable of maintaining unaltered the periodical movement, and the general speed will not admit of any further increase. For permanent speed we must therefore have

$$R = \frac{2}{\pi} P \dots (6).$$

This result shows that the general effect of the moving force P acting obliquely on OD at D is the same as if $\frac{2}{\pi} P$, or very nearly $\frac{7}{11} P$, were always applied perpendicularly at the same point; and this again is the same as if the force P itself were continually applied perpendicularly at a distance of $\frac{7}{11}$ ths of the radius ρ . This last distance is therefore the effective leverage of the crank.

It is not to be inferred from this that the effect of any portion of the power is lost. The quantity of power developed by a constant force is measured by the force multiplied into the distance through which it has acted. In a semi-revolution the power developed by P is hence $P \times 2\rho$; that expended by R would similarly be $R \times \pi\rho$; and, according to the equation (6), it appears that the expenditure would be the same in both cases, and that no loss is sustained through the obliquity of the action of the crank, except that which arises from the additional friction caused by the stress on the shaft.

Substitute the value of R by (6) in (5), and, for permanent speed, the angular velocity of the shaft of the engine at any period of the stroke is

$$\frac{d\alpha}{dt} = \sqrt{\frac{2P}{M} \left(c + x - \frac{2\rho}{\pi} \alpha \right)} \dots (7);$$

and for any position D from E to H , if β denote the angle $EO D$, this becomes

$$\omega = \sqrt{\frac{2P}{M} \left(c + \rho(1 - \cos.\beta) - \frac{2\rho}{\pi} \beta + (r - \sqrt{r^2 - \rho^2 \sin.^2 \beta}) \right)} \dots (8).$$

For a point D° in the returning half-stroke from H to E , if β denote the angle $HO D^\circ$, the value of AC' is obtained by substituting $\pi - \beta$ for α in the value of x expressed by equation (1), and is therefore

$$AC = \rho(1 + \cos.\beta) + (r - \sqrt{r^2 - \rho^2 \sin.^2 \beta});$$

and, if we deduct this from the whole distance $AB = 2\rho$, we get the expression for BC or x' , viz.

$$x' = \rho(1 - \cos.\beta) - (r - \sqrt{r^2 - \rho^2 \sin.^2 \beta}) \dots (9).$$

Therefore by equation (7) the velocity at D° is

$$\omega^\circ = \sqrt{\frac{2P}{M} \left(c + \rho(1 - \cos.\beta) - \frac{2\rho}{\pi} \beta - (r - \sqrt{r^2 - \rho^2 \sin.^2 \beta}) \right)} \dots (10).$$

The velocities ω' ω'' at D' D'' will now be determined by substituting $\pi - \beta$ for β in equations (10) and (8); thus we find

$$\omega' = \sqrt{\frac{2P}{M} \left(c - \rho(1 - \cos.\beta) + \frac{2\rho}{\pi} \beta - (r - \sqrt{r^2 - \rho^2 \sin.^2 \beta}) \right)} \dots (11),$$

$$\omega'' = \sqrt{\frac{2P}{M} \left(c - \rho(1 - \cos.\beta) + \frac{2\rho}{\pi} \beta + (r - \sqrt{r^2 - \rho^2 \sin.^2 \beta}) \right)} \dots (12).$$

To put these in a more simple form for comparison, let (ω) denote the velocity at E, as expressed by equation (a), and assume

$$\left. \begin{aligned} A &= \rho \left(\frac{2}{\pi} \beta - 1 + \cos. \beta \right) \\ h &= r - \sqrt{r^2 - \rho^2 \sin.^2 \beta} \end{aligned} \right\} \dots \dots \dots (13);$$

then, the angular velocities at any four corresponding points D° D D' D'' are

$$\left. \begin{aligned} \omega^\circ &= \sqrt{(\omega)^2 - \frac{2P}{M} (A + h)} \\ \omega &= \sqrt{(\omega)^2 - \frac{2P}{M} (A - h)} \\ \omega' &= \sqrt{(\omega)^2 + \frac{2P}{M} (A - h)} \\ \omega'' &= \sqrt{(\omega)^2 + \frac{2P}{M} (A + h)} \end{aligned} \right\} \dots \dots \dots (14);$$

which are here arranged respectively in the order of their magnitudes, that at D° being the least, and that at D'' the greatest.

These expressions may be put in a more convenient form by neglecting the higher powers of the small variations. We shall then have

$$\begin{aligned} \omega^\circ &= (\omega) - \frac{P}{M(\omega)} (A + h), \\ \omega &= (\omega) - \frac{P}{M(\omega)} (A - h), \\ \omega' &= (\omega) + \frac{P}{M(\omega)} (A - h), \\ \omega'' &= (\omega) + \frac{P}{M(\omega)} (A + h). \end{aligned}$$

But for h we may now substitute $\frac{\rho^2}{2r} \sin.^2 \beta$; therefore,

$$\left. \begin{aligned} \omega^\circ &= (\omega) - \frac{P}{M(\omega)} \left(A + \frac{\rho^2}{2r} \sin.^2 \beta \right) \\ \omega &= (\omega) - \frac{P}{M(\omega)} \left(A - \frac{\rho^2}{2r} \sin.^2 \beta \right) \\ \omega' &= (\omega) + \frac{P}{M(\omega)} \left(A - \frac{\rho^2}{2r} \sin.^2 \beta \right) \\ \omega'' &= (\omega) + \frac{P}{M(\omega)} \left(A + \frac{\rho^2}{2r} \sin.^2 \beta \right) \end{aligned} \right\} \dots \dots \dots (15);$$

in which the values of A in parts of ρ are by (13) found to be as follows:

β	A	β	A	β	A
0°	0.0000	30° +	.1994	60° +	.1667
5 +	.0518	35	.2080	65	.1448
10	.0959	40	.2105	70	.1198
15	.1326	45	.2071	75	.0922
20	.1619	50	.1984	80	.0625
25	.1841	55	.1847	85 +	.0316
30 +	.1994	60 +	.1667	90	0.0000

From these last expressions we conclude that the velocity (ω) which occurs at E and H is the *mean velocity*, and that the greatest and least velocities occur in the quadrants of D'' and D°, at the points where $A + \frac{\rho^2}{2r} \sin.^2 \beta$, or $\frac{2}{\pi} \beta + \cos. \beta + \frac{\rho}{2r} \sin.^2 \beta$, attains its maximum value. If we assume these points to be in the middle of the respective quadrants, so that $\beta = 45^\circ$, which will be very nearly the case with all the proportions observed in practice, and cannot sensibly affect the accuracy of the results, the greatest and least velocities will be $(\omega) \pm \frac{P\rho}{M(\omega)} \left(\frac{\rho}{4r} + 0.207 \right)$, and the deviation from the mean value will be

$$\frac{P\rho}{M(\omega)} \left(\frac{\rho}{4r} + 0.207 \right).$$

Again, by substituting the values of P', R, the force P' - R, which at each position tends to accelerate the motion, is found to be

$$P' - R = P \left\{ \sin. \alpha \left(\frac{\rho \cos. \alpha}{\sqrt{r^2 - \rho^2 \sin.^2 \alpha}} + 1 \right) - \frac{2}{\pi} \right\} \dots \dots (16).$$

It hence appears that the motion is

$$\left. \begin{array}{l} \text{accelerated} \\ \text{retarded} \end{array} \right\} \text{ when } \sin. \alpha \left(\frac{\rho \cos. \alpha}{\sqrt{r^2 - \rho^2 \sin.^2 \alpha}} + 1 \right) \text{ is } \left\{ \begin{array}{l} \text{greater} \\ \text{less} \end{array} \right\} \text{ than } \frac{2}{\pi} \text{ or } 0.63.$$

Values of this expression are shown in the Table given at the end of the article on 'Crank' in the present work.

In the preceding investigation we have only considered the action of a single crank; but it will be found to apply, with a slight modification, when the rotary force of the shaft is maintained by the action of any number of cranks making given angles with each other. We have only to substitute, in place of P', in the right-hand member of the equation of motion, the sum of the forces P' arising from the several cranks; and, by following out the same process, the equation (5) will become

$$\frac{d\alpha}{dt} = \sqrt{\frac{2}{M} \left\{ P c + \Sigma (P x) - R \rho \alpha \right\}},$$

in which $\Sigma (P x)$ includes the same term for each crank. Let (ω) denote the

value of this angular velocity when $x = 0$, $a = 0$, and the expression, for any other position, will hence be

$$\omega = \sqrt{(\omega)^2 + \frac{2}{M} \left\{ \sum (Px) - R_p \alpha \right\}} \dots \dots (17).$$

By attending to the nature of the integration, it is evident that this equation applies generally from any assigned position throughout the entire period of each revolution of the shaft, if we give to the symbols x a the following signification, viz.

x , the *entire* distance travelled over by the extremity C, } each being estimated from that position in
 for each crank ; } which the velocity was (ω).
 α , the angle described by the revolution of the shaft ; }

Let us take the practical case, in which the revolution of the shaft is maintained by a pair of equal engines, and in which the equal arms of the two cranks are placed at right angles, so that each of them may be in full action when the other is 'on the centre.' If we suppose one entire revolution to be performed, the distances x traversed by the extremity of each connecting rod will be 4ρ , the angle α described will be 2π , and the velocity will become

$$\omega = \sqrt{(\omega)^2 + \frac{2}{M} (4 P_{\rho} + 4 P_{\rho} - 2 R_{\rho} \pi)} = \sqrt{(\omega)^2 + \frac{4 \rho}{M} (4 P - R \pi)}.$$

When the engines have attained their regular speed, this velocity must correspond with (ω) , since precisely the same motions must recur in successive revolutions; we must hence have $4 P - R \pi = 0$,

$$\therefore R = \frac{4}{\pi} P \dots \dots (18).$$

This value is the same as $\frac{2}{\pi} (2 P)$, in which $2 P$ is now the moving power, and we observe that it corresponds with the expression (6) for the single crank.

To find a more convenient expression for the velocity at any position, let x be the distance traversed by the connecting rod of that crank which takes the lead in the direction of rotation, and y the corresponding distance traversed by the connecting rod of the other crank which follows it. Then, substituting the value of R , &c., in (17), we have

$$\omega = \sqrt{(\omega)^2 + \frac{2P}{M} \left(x + y - \frac{4\rho}{\pi} \alpha \right)} \dots \dots (19).$$

We will now suppose the advancing crank to proceed from the point E with the angular velocity (ω), and to pass over to the four successive positions D, D'', D°, D', equidistant from the diameter E H. The other crank will proceed

from the point F, and always be 90° or $\frac{\pi}{2}$ behind the former. Let β denote the arc ED or HD'', and assume

$$\left. \begin{aligned} h &= r - \sqrt{r^2 - \rho^2 \sin.^2 \beta} \\ k &= r - \sqrt{r^2 - \rho^2 \cos.^2 \beta} \\ m &= r - \sqrt{r^2 - \rho^2} \end{aligned} \right\} \dots\dots (20).$$

Then we shall have, for the point D, $x = \rho (1 - \cos. \beta) + h$,

$y = \rho + m - \rho (1 - \sin. \beta) - k$; for the point D'', $x = \rho (1 + \cos. \beta) + h$,

$y = \rho + m + \rho (1 - \sin. \beta) + k$; for the point D°, $x = 4\rho - \rho (1 + \cos. \beta) - h$,

$y = \rho + m + \rho (1 + \sin. \beta) + k$; and for the point D', $x = 4\rho - \rho (1 - \cos. \beta) - h$,

$y = \rho + m + 4\rho - \rho (1 + \sin. \beta) - k$. Hence the sum of the distances $x + y$ takes the following values,

$$\begin{aligned} \text{at D, } x + y &= \rho (1 - \cos. \beta + \sin. \beta) + m + h - k, \\ \text{,, D'', } &= \rho (3 + \cos. \beta - \sin. \beta) + m + h + k, \\ \text{,, D°, } &= \rho (5 - \cos. \beta + \sin. \beta) + m - h + k, \\ \text{,, D', } &= \rho (7 + \cos. \beta - \sin. \beta) + m - h - k. \end{aligned}$$

Also, for these four points the angles described are respectively $\beta, \pi - \beta, \pi + \beta$, and $2\pi - \beta$, which must likewise be severally substituted for a in (19). Performing these substitutions, and making

$$A = \rho \left(\frac{4}{\pi} \beta - 1 + \cos. \beta - \sin. \beta \right) \dots\dots (21),$$

we find, for the four respective points just enumerated,

$$\left. \begin{aligned} \omega &= \sqrt{(\omega)^2 + \frac{2P}{M} (m - A + h - k)} \\ \omega'' &= \sqrt{(\omega)^2 + \frac{2P}{M} (m + A + h + k)} \\ \omega^\circ &= \sqrt{(\omega)^2 + \frac{2P}{M} (m - A - h + k)} \\ \omega' &= \sqrt{(\omega)^2 + \frac{2P}{M} (m + A - h - k)} \end{aligned} \right\} \dots\dots (22).$$

These expressions may be considerably simplified by disregarding the powers of the small variations above the first. In the first place we immediately obtain

$$\omega = (\omega) + \frac{P}{M(\omega)} (m - A + h - k),$$

$$\omega'' = (\omega) + \frac{P}{M(\omega)} (m + A + h + k),$$

$$\omega^\circ = (\omega) + \frac{P}{M(\omega)} (m - A - h + k),$$

$$\omega' = (\omega) + \frac{P}{M(\omega)} (m + A - h - k).$$

But the values of $h k m$ in (20) will now become $h = \frac{\rho^2}{2r} \sin.^2 \beta$, $k = \frac{\rho^2}{2r} \cos.^2 \beta$ and $m = \frac{\rho^2}{2r}$. We have finally, therefore,

$$\left. \begin{aligned} \omega &= (\omega) + \frac{P}{M(\omega)} \left(\frac{\rho^2}{r} \sin.^2 \beta - A \right) \\ \omega'' &= (\omega) + \frac{P}{M(\omega)} \left(\frac{\rho^2}{r} + A \right) \\ \omega^o &= (\omega) + \frac{P}{M(\omega)} \left(\frac{\rho^2}{r} \cos.^2 \beta - A \right) \\ \omega' &= (\omega) + \frac{P}{M(\omega)} (A) \end{aligned} \right\} \dots\dots (23).$$

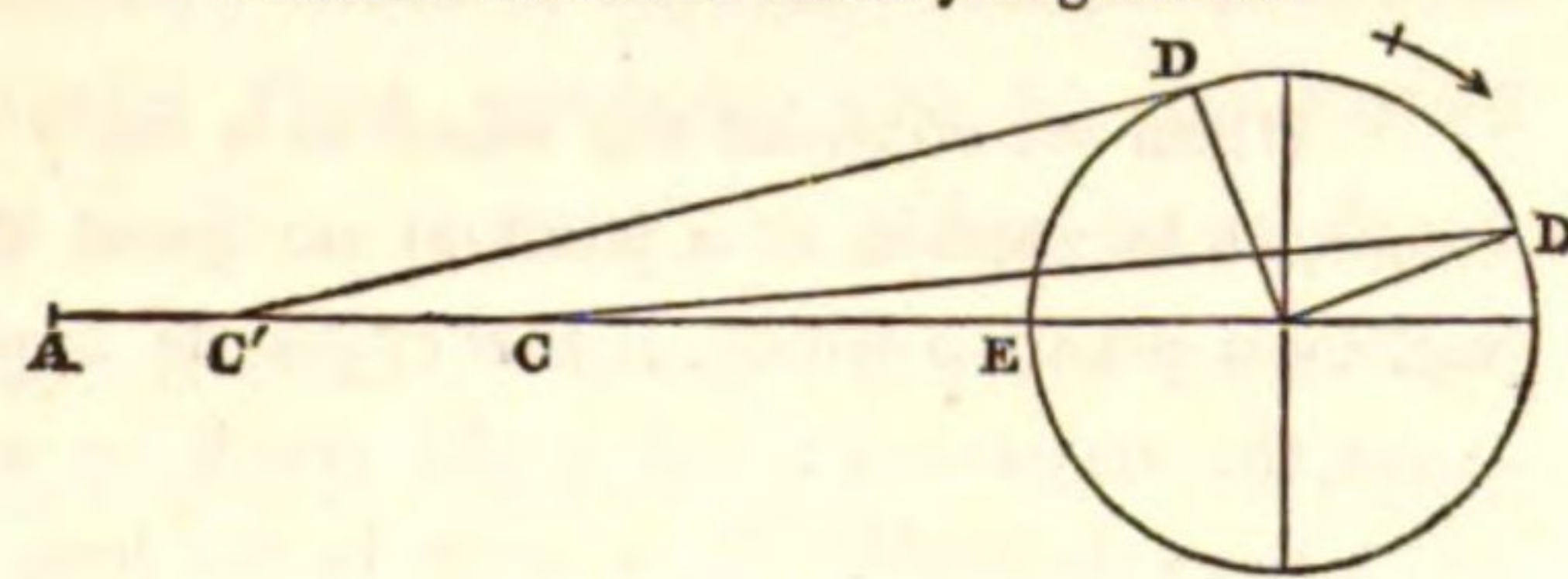
The expression (21) gives to A the following values in parts of ρ for every fifth degree of the arc β :

β	A	β	A	β	A
0°	0.0000	$30^\circ +$	0.0327	$60^\circ -$	0.0327
5 +	0.0201	35	0.0234	65	0.0393
10	0.0334	40 +	0.0121	70	0.0421
15	0.0404	45	0.0000	75	0.0404
20	0.0421	50 -	0.0121	80	0.0334
25	0.0393	55	0.0234	85	0.0201
30 +	0.0327	60 -	0.0327	90	0.0000

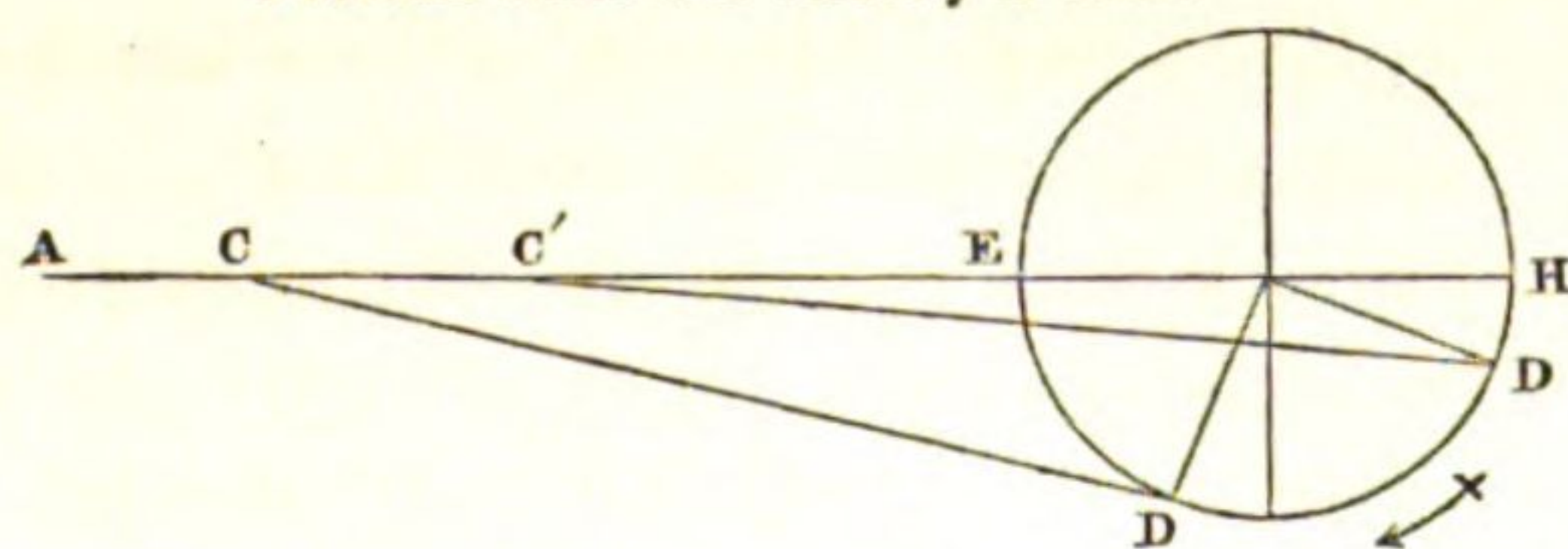
On examining the values (23) we observe that the greatest velocity takes place in the quadrant of D'' , and at the point where A attains its greatest positive value, viz. at 19° from H ; we also perceive that the least velocity occurs in the quadrant of D' , and at the point where A attains its greatest negative value, viz., at 71° from E ; and that the mean angular velocity is $(\omega) + \frac{P}{M(\omega)} \cdot \frac{\rho^2}{2r}$. We have, therefore,

$$\left. \begin{aligned} \text{Maximum} \\ \text{Minimum} \end{aligned} \right\} \text{value of } \omega = \begin{cases} (\omega) + \frac{P\rho}{M(\omega)} \left(\frac{\rho}{r} + 0.042 \right) \\ (\omega) - \frac{P\rho}{M(\omega)} (0.042) \end{cases}$$

Position when the velocity is greatest.



Position when the velocity is least.



$$\left. \begin{aligned} \text{Greatest deviations} \\ \text{from mean value} \end{aligned} \right\} = \frac{P\rho}{M(\omega)} \left(\frac{\rho}{2r} + 0.042 \right)$$

and these occur in the positions represented in the figures annexed. For only one engine and crank we have before found the greatest deviation from the

mean angular velocity to be $\frac{P' \rho}{M(\omega)} \left(\frac{\rho}{4r} + 0.207 \right)$, in which, for the moment, we accentuate the symbol P , because in this case it represents the entire acting power, whereas in (25) it represents only the power of one of the two engines; and, under like circumstances, we have $P' = 2P$, so that the latter expression becomes $\frac{P \rho}{M(\omega)} \left(\frac{\rho}{2r} + 0.414 \right)$. Comparing this with (25) it appears that the variation of velocity with a single engine and one crank, and the variation of velocity with a pair of engines and two cranks, are to each other in the ratio of $\frac{\rho}{r} + 0.818$ to $\frac{\rho}{r} + 0.082$, which ratio varies from about 3 to 1 up to that of 10 to 1.

These results are of much value in pointing out the effects to be produced by varying the radius of the crank, the length of the stroke, and the diameter of the cylinder. All other circumstances being the same, the values $P \rho$, $M(\omega)$ will be constant; and therefore the extreme variation of velocity will always be proportional to $\frac{\rho}{r} + 0.828$ for one crank, or $\frac{\rho}{r} + 0.084$ for two cranks acting alternately in the usual way. Hence it follows, that by diminishing the radius of the crank and increasing the length of the connecting rod, the irregularity of the movement will be materially diminished, more particularly when two engines are employed. It is on this account highly desirable to have as long a connecting rod as convenient, in proportion to the radius of the crank; while, on the other hand, it adds another to many important objections against the adoption of the American proportions recommended by Professor Renwick,¹ to employ a crank of large radius and a long cylinder, since the disagreeable and destructive jolting experienced in the working of engines is principally due to the irregularity of action here alluded to.

We have gone thus far into an investigation of the motion of the crank, as it

¹ When we consider the wheel as a body revolving on an axis, which meets with a resistance whose resultant is applied to a point at no great distance from its circumference, it will be obvious that there will be a point to which, if the crank be applied, the whole force of the engine will be exerted to overcome the resistance; but if the crank be applied to any other point, a part of the force will be wasted upon the axle itself. Now, even in the long stroke usual in the modern American engines, it does not appear that the crank extends as far as this most favourable point; but in the short stroke of the English engines a large proportion of the whole power is lost. This advantage is, however, at present less sensible in the American steam boats; for the principle of using cylinders of great length having been introduced, the next step was to increase the diameters of the wheels. The object intended to be gained by the latter change was an increase in the velocity of the circumference of the wheel, for the constructors of steam boats seemed to have reached the conclusion that every addition to this velocity would add as much to that of the vessel. In one instance the diameter of the water-wheels has been increased to thirty feet, and the stroke of the piston to twelve feet.—*Renwick on the Steam Boats of the United States* (p. 109, *Appendix to previous edition of this work*).

forms one of the most important instruments of the steam engine, and has hitherto met with very little attention from scientific writers. It is, doubtless, the most simple, and perhaps the most efficient, contrivance that can be devised to convert a reciprocating action into a rotatory motion; and in this respect we cannot be surprised that it has not been superseded by any one of the numerous inventions that have been proposed with a view of dispensing with it. We are compelled, however, at the same time, to admit that this beautiful simplicity is accompanied by corresponding inconveniences in the inequalities of motion, pressure, friction, and consequent wear. The mechanical defects of engines constructed on the rotatory principle appear to be of greater magnitude, and the disadvantages and difficulties that stand in the way of their application to the most important uses are of a very formidable nature. This is much to be regretted, as we conceive a perfectly equable motion to be a great desideratum in the steam engine, and the only hope we can have of succeeding in obtaining it is in the exclusive employment of rotary action. On this head we may refer our readers to an instructive paper, entitled 'On the Fallacies of the Rotatory Steam Engine,' by Mr. John Scott Russell. One of the leading objects of this paper, which is printed in the 'Edinburgh New Philosophical Journal' for January, 1838, is to show that no loss of power is sustained by the intervention of the crank; but, in doing this, it should be remarked, that the author has throughout his paper discussed only the particular case in which the moving power acts on the crank in parallel lines, or in which the connecting rod is supposed to be of infinite length; and that this necessarily reduces many of his statements into mere approximations, when the subject is generally considered. Mr. Russell has, however, handled the subject with considerable power, and his remarks are, perhaps, sufficiently precise for the object he had in view, viz., to dispel the delusion under which many practical men labour with respect to the nature of the crank,—that it is attended with a loss of nearly one-third of the power. It is well known that persons are to be found who have been the subjects of this delusion, as well as inventors who have been its victims, but we cannot concur with Mr. Russell that "some eminent standard writers on the steam engine have advanced the same doctrines." Most writers who are accustomed to treat these matters scientifically have doubtless considered that no reasonable dispute could possibly be entertained, and have thought it unnecessary to make any declaration on the point in question. We may, however, be allowed to refer to one exception. At page 137 of Hann and Dodd's 'Mechanics for Practical Men,' the very question is taken up, and comprehensively disposed of, in the following paragraph:

"In the crank, as applied in the steam engine, the effect which is produced, is to the effect, were the force to act perpendicularly on the crank all the way

round, as twice the diameter of a circle is to the circumference; in consequence of which, many practical men have considered that there is a corresponding loss of power by using a crank; without ever considering that the piston, or moving power, only moves through twice the diameter of the crank's orbit, while the crank moves through its whole circumference. For here the same principle holds good as in all other mechanical contrivances, viz., the power multiplied by the space which it passes over, is equal to the weight or resistance multiplied by the space which it passes over."

These statements have since found their way into other mechanical works of more recent date; and it is certainly of some moment that practical men who have not the means of following out theoretical investigations of these subjects, should be thus guarded from an error by which many of them have been so widely misled. That no power is gained or lost by the use of the crank has already been established on dynamical principles at the commencement of this paper. We are not, however, to conclude that this principle is at all peculiar to the crank. It is well known to apply to every combination of the five elementary powers, and by the principle of virtual velocities it may easily be shown that it is an universal property of mechanical arrangement, *that with every possible mechanical combination, no power can be gained or lost, if we except the resistances occasioned by friction.*

II. — PRINCIPLE OF LIVING FORCES.

The quantity of power expended in the production or maintenance of any effect is, however, most simply determined by the general principle of living forces. This principle, which is immediately deducible from that of virtual velocities, is applicable to every possible motion of terrestrial bodies, and may be enumerated as follows:

At any instant let each particle of the system be multiplied into the square of its velocity, and the product will be the living force of the particle. The aggregate of all these products will measure the total amount of impetus or living force of the system.

Let each force Q , acting at a particular point, be multiplied into the small distance $d q$ traversed by that point, in the direction of the line in which the force acts, during an elementary instant of time $d t$, and the product will measure the expenditure of power during that instant. In this measurement, the forces or pressures arising from the connexion of the parts will be neglected, because no motion can at any instant be produced in the direction of such pressures, and they consequently can have no share in the generation or consumption of living

force; but the resistances of friction, which are proportional to the pressures on the parts, and act in the direction of the motion, must be regarded. In the cases where the point moves in the direction of the force, the effect will be to increase the living force; but in the cases where the point moves in the contrary direction, the effect will be to diminish the living force, and all resistances are of this latter description.

Now, if from double the total expenditure towards the increase of the living force we deduct double the total expenditure towards its diminution, each being so estimated, the difference will always accurately express the variation that takes place, during the instant dt , in the above-defined value of the living force of the system.

The sum of the variations through successive instants will express the total variation that takes place in a finite time. When the forces are variable, this summation must be effected by the integral calculus; but when the forces are constant, it will only be necessary to multiply each into the whole distance traversed by its point of application in the direction of its action, to get its effect in any given time or space.

When the motion is permanent and the velocities recur at stated periods, the whole variation of living force through the extent of each period must evidently be zero; and hence in this case the expenditure of the moving powers must be precisely equal to that of the resistances throughout an entire period.

This principle, though exceedingly general, is of very easy application, and it will readily be perceived how the preceding theories of the action of the crank, or indeed of any other action, may be immediately deduced from it.

It may be here worthy of remark, that in the case of steam employed at a given temperature, the density being inversely as the pressure, the expenditure of the moving power of the piston will be proportional to the quantity of steam consumed or the effective quantity of water evaporated.

III. — TRANSMISSION OF EFFECT FROM THE CYLINDER.

The principle that no power can be gained or lost in its transmission by means of mechanism, enables us without much difficulty to trace the effective working of an engine due to a given pressure in the cylinder.

Let a denote the diameter of the cylinder in inches.

l „ the length of the stroke in feet.

τ „ the temperature of the steam in the cylinders.

P „ its mean pressure in lbs. per square inch.

Let F denote the entire friction, estimated on the pistons, in lbs. per square inch.

For high-pressure engines this must include the pressure of the atmosphere.

R ,, the resistance, in lbs., overcome at the extremity of the two wheels connected with the shaft.

n ,, the number of strokes per minute.

u ,, the velocity of the piston in feet per minute.

V ,, the velocity of the circumference of the wheel in feet per minute.

π ,, 3.14159, &c.

Then if Q denote the force on the pistons which would just overcome the resistance R , we shall have, equating their powers, $Q u = R V$; and therefore $Q = \frac{V}{u} R$. The area of the two pistons being $\frac{\pi}{2} a^2$ square inches, the pressure per inch just sufficient to overcome the resistance will be $q = \frac{Q}{\frac{\pi}{2} a^2} = \frac{2 Q}{\pi a^2} = \frac{2 V}{\pi a^2 u} R$. To this

add the friction F , and the entire pressure per square inch on the pistons is hence

$$P = \frac{2 V}{\pi a^2 u} R + F \dots (A).$$

But since V passes through πD , a circumference of the wheel, and u passes through $2 l$, twice the length of the stroke, in each revolution, $\frac{V}{u} = \frac{\pi D}{2 l}$; and this being substituted in (A), we get

$$P = \frac{D}{a^2 l} R + F \dots (B);$$

and hence

$$F = P - \frac{D}{a^2 l} R \dots (C),$$

$$R = \frac{a^2 l}{D} (P - F) \dots (D);$$

which express the relations amongst the mean forces or pressures P , F , R .

The velocities of the parts of the engine depend on the number of strokes, that of the piston being

$$u = 2 n l \dots (E).$$

Also the number of horses' power on two cylinders, according to Tredgold's general rule, pp. 205-6, is found to be

$$H = \frac{\frac{\pi}{2} a^2 P \times 2 n l}{33000},$$

$$\text{or } H = \frac{\pi n a^2 l P}{33000} \dots (F).$$

The numerator of this expression represents the quantity of steam ($\pi n a^2 l$) consumed per minute multiplied into the pressure (P) at which it is supplied to the cylinder; and, the temperature τ being supposed to be preserved, this product, in fact, expresses the evaporating power of the boiler, including, of course, the necessary reductions for the unavoidable losses by the passage of the steam through the steam-pipe, the clearance of the cylinder, &c.; and it hence also appears that the effective evaporating power of an engine is proportional to the number of horses' power.

The equation (F) gives also

$$n P = \frac{33000 H}{\pi a^2 l} \dots (G).$$

Thus it appears, that when the engine is working at a given power, the number (n) of strokes per minute will vary inversely as the mean pressure P on the piston, which is a principle particularly applicable to the motion of Locomotive Engines, where the forces P , R , are subject to considerable variations.

The special relations of the motion of locomotive engines have been ably treated by the Comte F. M. G. De Pambour. From numerous experiments with different engines on the Liverpool and Manchester Railway, made under the author's inspection, with the view of ascertaining the amount of friction, he has arrived at the following useful conclusions, respecting the resistance to traction, which may be regarded as approximate estimations for locomotive engines as at present constructed, viz.

1. That the average tractive friction of the carriages, without the engine and tender, may be reckoned at 8 lbs. per ton of the entire weight of the carriages and load.

2. That the average friction or resistance to traction of well-constructed locomotive engines, in good order, is about 15 lbs. per ton of their weight.

3. That the tractive friction of the engine is increased by the load at an average of about 1 lb. per ton.

We may hence add,

4. That the friction of the wheels alone of an engine, by the first estimation, being 8 lbs. per ton of its own weight, the friction due to its own weight as a load being 1 lb. per ton, and the whole resistance being 15 lbs. per ton, it follows that the friction of the engine gear alone, independently of any connexion with the rails, is, on the average, about 6 lbs. per ton of the weight of the engine applied at the circumference of the wheel.

5. That the entire resistance to an engine and train may be estimated at 9 lbs.

per ton on the gross weight of the engine, tender, carriages, and load, increased by 6 lbs. per ton on the weight of the engine alone.

IV. — TRANSMISSION FROM THE BOILER TO THE CYLINDER.

M. Pambour professes to determine the velocities on considerations of a novel nature, which may be briefly explained, thus: If the evaporating power of the boiler be capable of supplying a greater quantity of steam, at the required pressure, than is consumed at the successive strokes of the piston, it is evident that the pressure of the steam in the boiler will gradually increase, provided no portion is supposed to escape through the safety-valve or otherwise. This increasing pressure will gradually accelerate the velocity; and finally, when the engine attains her permanent speed, the quantity of steam consumed in the cylinder and supplied through the steam-pipe must evidently correspond with the quantity evaporated by the boiler. Thus he pretends to introduce a new element into the calculation, viz., the evaporating power of the boiler, which again is to be estimated by the quantity of fire surface; and, the density of steam at a given temperature being, according to the law of Boyle and Mariotte, proportional to the pressure and inversely as the volume, as in the case of gases, the evaporating power is measured by the volume of steam, generated in a given time, multiplied into its pressure. We submit, however, that M. Pambour is mistaken if he supposes such a mode of proceeding to involve any new doctrine, or any principle that had not already been laid down by Mr. Tredgold in the first edition of this work. In support of this statement we need only refer to the equations (F), (G), which are founded on Tredgold's well-known rule for calculating the power of an engine, and from which it will appear that he measures the power by the quantity of steam effectively consumed in the cylinder per minute, multiplied into its pressure. Indeed, the preceding equations (A), (B), (C), (D), (E), (F), (G), which are strictly in accordance with the principles laid down by Tredgold, constitute the whole of our scientific information on the power of the steam engine that has hitherto been established on theoretical principles. No scientific theorist or experimentalist has yet satisfactorily ascertained the laws which regulate the transmission of the steam from the boiler to the cylinder,¹ and we cannot, therefore, be surprised that

¹ It is impossible that this difficulty can ever be properly surmounted until we first determine either the specific heat of steam, or the whole quantity of heat contained in a given volume of steam at a given temperature and pressure. A decisive step towards the solution of this most important problem has been effected by E. Clapeyron, in a Memoir inserted in the 'Journal de l'Ecole Royale Polytechnique,' vol. xiv. page 153. The investigation is conducted on a principle which to all appearance is deserving of

Tredgold has treated this part of the subject in a very slight and imperfect manner, which has especially been objected to by the Comte De Pambour, in his 'Memoir on the Steam Engine,' some time ago published in the form of a pamphlet, and since embodied in his larger work, 'The Theory of the Steam Engine,' 8vo, 1839; and we have every reason to suppose that they were all of them approximate estimations for the work of such engines as Mr. Tredgold had access to for his experience, which, in reference to engines now constructed, were no doubt of very limited dimensions and power, and of comparatively inferior workmanship. There can be no doubt that estimations of this kind, where a fixed proportion of the whole power is taken, are not to be depended upon. It cannot, however, be overlooked that M. Pambour, in throwing discredit on what he terms the ordinary theory, has unfairly applied the principle of constant co-efficients in such a way as had never been contemplated by Tredgold or any one else; besides, it should be observed, that M. Pambour has only evaded the difficulty in another way: he has estimated the friction and losses in a manner more in accordance with the nature of the steam engine, but, nevertheless, equally as empirical as that of Tredgold; and the state of the problem remains nearly the same as it did before. For instance, in his 'Treatise on Locomotive Engines,' he takes the effective evaporation through the cylinders at 3-4ths of the total evaporation in the boiler, viz. the effective evaporating power 0.3 cubic foot, and the total evaporating power 0.4 cubic foot of water, for each square foot of surface exposed to the fire. On the whole, we are compelled to conclude that such estimations are not to be relied upon as general rules; that where accuracy is really wanted, the actual amount of loss, &c. is only to be estimated by having recourse to the experience of each individual description of engine under given circumstances; and that the correct value of the effective power of an engine is only to be found in the mean pressure on the piston, and the velocity with which it moves, according to the old rule.

credit, viz., that no power can possibly be created or generated without the transmission of a portion of heat, and that the amount of power must be wholly independent of the nature of the medium of transmission. The latter condition depends on the former; for if the power developed varied with the nature of the medium, the quantity of heat being transmitted by one medium and returned by another, a portion of power might be so gained or lost without any resulting or effective transmission. In this principle it is of course assumed that no loss of power or *vis viva* is occasioned by contact of bodies of different temperatures. The application of it is very ingenious, and leads to the following expression for the whole quantity (Q) of heat contained in a volume (v) of steam at the pressure (p), viz.

$$Q = f(p \cdot v) - F(p \cdot v) \text{ hyp. log. } p,$$

in which $f(p \cdot v)$, $F(p \cdot v)$ denote functions of the product ($p \cdot v$) of the pressure and volume, the nature of which functions still remains to be determined before the solution can be considered to be complete. It is found by experiments, that the latter function increases gradually with the temperature.

There is one more point in M. Pambour's strictures on Tredgold's principles which it may be necessary to notice, being one on which he has, by some sort of inattention, allowed himself to be grossly deceived. The point in question, which, on being misrepresented, might possibly mislead others, is involved in the following extract from page 9 of his 'Memoir on the Steam Engine :'

"Tredgold, in his 'Treatise on Steam Engines,' undertakes to calculate the velocity of the piston from considerations deduced from the velocity of the flowing of a gas, supposed under a pressure equal to that of the boiler, into a gas supposed at the pressure of the resistance. He concludes from thence, that the velocity of the piston would be expressed by this formula,

$$V = 6.5 \sqrt{h},$$

in which V is the velocity in feet per second, and h stands for the difference between the heights of two homogeneous columns of vapour, one representing the pressure in the boiler, the other that of the resistance. But it is easily seen, that this calculation supposes the boiler filled with an inexhaustible quantity of vapour, since the effluent gas is supposed to rush into the other with all the velocity it is susceptible of acquiring, in consequence of the difference of pressure. Now such an effect cannot be produced, unless the boiler be capable of supplying the expenditure, however enormous it might be. This amounts consequently to supposing that the production of steam in the boiler is unlimited. But, in reality, this is far from being the case. It is evident that the velocity of the piston will soon be limited by the quantity of steam producible by the boiler in a minute. If that production suffice to fill the cylinder 200 times in a minute, there will be 200 strokes of the piston per minute; if it suffice to fill it 300 times, there will be 300 strokes. It is then the vaporization of the boiler which must regulate the velocity, and no calculation which shall exclude that element can possibly lead to the true result; consequently the preceding formula cannot be exact.

"This is why, in applying this formula to the case of an ordinary locomotive engine of the Liverpool Railway with a train of 100 tons, the velocity the engine ought to assume is found to be 734 feet per second, instead of 20 miles an hour, or 30 feet per second, which is its real velocity."

On reference to the article alluded to, it will at once be perceived that these remarks are based entirely on M. Pambour's own misconception of what Tredgold has really given. The formula in question has no reference whatever to the velocity of the piston. It will be observed, that instead of the velocity of the piston, it is distinctly given as the velocity of the steam through the steam-pipe, and that the sole object of Tredgold's inquiry is not velocity at all, but merely the determination of the requisite aperture of the steam-pipe! This sufficiently

accounts for M. Pambour having puzzled himself with the case of the Liverpool Railway locomotive engine, and leaves us with the full assurance that Tredgold was too well acquainted with the nature of his subject to allow himself to wander so immeasurably from the truth as M. Pambour had supposed.

We have not made the preceding remarks with any view to the disparagement of what the Comte De Pambour has done towards our knowledge of the steam engine, which we by no means hold to be unimportant: he is evidently well versed in the practical nature of its action; he has, doubtless, furnished the best set of experiments on locomotive engines, and his general remarks embody much sound and valuable information on that subject. We cannot, however, admit that he has made any important advance in the mathematical theory of the steam engine, much less that he has brought it to absolute perfection; and so long as the theory remains incomplete, we must continue to make certain estimations by assumed and approximate rules. It is fortunate, however, that the theory of transmission from the boiler to the cylinder and other points, which Tredgold left untouched, and which are still open for future investigation, are matters that may be practically dispensed with.

PRACTICAL RULES FOR CALCULATING THE STEAM ENGINE.

BY THE SAME AUTHOR.

[The number inserted at the end of each rule refers to the page of the book where information respecting it is to be found.]

PROPERTIES OF STEAM.

THE additional heat required for the formation of steam may be estimated at 1000° Fahr., the heat of conversion from liquid to vapour.

1. To find the elastic force of steam when in contact with the liquid from which it is formed, the temperature being given.

Tredgold's Rule.

RULE 1.—Add 100 to the temperature, in degrees, and from the logarithm of this sum subtract 2.24797; then multiply by 6, and the product will be the logarithm of the force in inches of mercury. (16.)

Example.—Let the proposed temperature be 250° Fahr.

Temperature	250	
Add	100	
350 . . . log.	2,54407 ¹	
Subtract by the Rule	2,24797	
Difference	0,29610	
Multiply by	6	
Log. 59·8	1,77660	

The required force is therefore 59·8 inches of mercury.

Southern's Rule.

RULE II.—Add 51·3 to the temperature, and multiply the logarithm of the sum by 5·13; from the product deduct 10·94123 and find the natural number answering to the remainder as a logarithm: this number, increased by 0·1, will express the required pressure in inches of mercury. (15.)

Example.—Take the same as before.

Temperature	250	
Add	51·3	
301·3 . . . log.	2·47900	
Multiply by	5·13	
	743700	
	247900	
	1239500	
	12·7172700	
	10·94123	

Corresponding number 59·7 . . . 1·77604

To be increased by 0·1

Required force 59·8 inches of mercury.

This Rule appears to be preferable for high temperatures.

The force in inches of mercury may be reduced to lbs. on the square inch by dividing successively by 2, 6, and 9, and subtracting the third quotient from the first, thus:

2) 59·8 inches of mercury,	
6) 29·9	
9) 4·98	
	0·55
	29·35 lbs. per square inch.

¹ When the water is salt, refer to the last column of the Table, page 36, for this logarithm.

2. To find the volume or space the steam of a cubic foot of water occupies when the steam is of a given elastic force and temperature, and separated from the liquid from which it is generated.

RULE I.—To the temperature, in degrees, add 459, and multiply the sum by 76.5; divide the product by the force of the steam in inches of mercury, and the result will express the space in cubic feet which the steam of a cubic foot of water will occupy. (76.)

Example.—Let the force be 4 atmospheres, or 120 inches of mercury, and the temperature 295°.

Temperature	295
Add	459
	754
Multiply by	76.5
	3770
	4524
	5278
	57681.0

Force in inches of mercury 120) 57681.0 (481 cubic feet, the volume of the steam from a cubic foot of water.

480	
968	
960	
81	

RULE II.—To the temperature, in degrees, add 459, and multiply the sum by 38; divide the product by the pressure in lbs. per square inch. (76.)

Same Example.

Temperature	295
Add	459
	754
Multiply by	38
	6032
	2262
	28652
lbs. per inch 59)	28652 (486 cubic feet.
	236
	505
	472
	332

BOILERS.

3. To find the dimensions of a boiler for a given power.

I. Rectangular or Watt's Boiler, when it has no internal flues.

RULE.—The bottom surface should be about 5 feet for each horse-power. (124.) Take the capacity of the boiler for water, and divide it by the quantity of bottom surface, and the quotient will be the depth of water.

Divide twice the capacity for water less the area of the bottom surface by the side surface for fire and flue, and the result will be one of the dimensions of the bottom. Divide the bottom surface by this dimension, and it gives the other. (125.)

Example.—To find the proportions of a boiler for an engine of 12 horse-power, the capacity for water being 12·2 cubic feet for each horse-power.

Horse-power	12	Cubic feet per horse-power	12·2
Table, page 124,	5	Horse-power	12
Bottom surface	60	Capacity	146·4
Horse-power	12	6,0) 14,6·4, capacity	
Table, page 124,	4·9		2·44, depth of water.
Side surface	58·8 or 59.		
Double the capacity	292·8		
Subtract bottom surface	60·0		
Divide by side surface 59)	232·8 (4 feet, one of the dimensions of the bottom.		
	236		
	4) 60 (15 feet, the other dimension.		

N.B. It cannot be of much importance that the dimensions should be in the proportion of 4 to 15, so long as the quantity of bottom surface is 60 square feet.

II. Cylindrical Boilers, with the fire applied externally.

RULE.—Let the capacity for water and for steam be added together, and also the quantities of fire surface; then divide twice the capacity by the quantity of fire surface, and the result will be the diameter. (127.)

Also, 1·27 times the capacity divided by the square of the diameter will give the length.

Example.—Required the dimensions of a cylindrical boiler for a 12 horse-power, the whole capacity being 293 cubic feet?

Table, page 124, for {	Bottom surface	5·0
	Side surface	4·9
		9·9
	Horse-power	12
	Fire surface	118·8 or 119.

Capacity 293
 2
 Fire surface 119) 586 (5 feet, the diameter.

Capacity 293
 1.27
 2051
 586
 293
 Square of diameter = 25) 372.11 (14.9 or 15 feet, the length.

25
 122
 100
 221
 225

4. To find the requisite thickness for a rectangular or cylindric boiler.

RULE.—Multiply the load in lbs. per square inch on the safety-valve by the greatest diagonal of the section of the boiler in inches, and divide the product by

150 } times the cubic feet of boiler per horse-power, for { wrought iron ;
 90 } { copper ;

the result will be the thickness of the upper plates in inches.

The bottom plates should be as much thicker as will compensate for wear; usually twice the thickness of the top ones.

Example.—In a rectangular boiler, the greatest diagonal being 8 feet 2 inches = 98 inches, the load on the valve 6 lbs. per square inch, and the space for steam for each horse-power 18 cubic feet; required the thickness of the top plates, to be made of wrought iron?

18 cubic feet	98 inches
150	6 lbs.
900	27 00) 5 88 (0.218 of an inch for the top plates.
18	54
2700	48
	27
	210

The bottom plates should be the double of 0.218 or 0.436 of an inch.

5. To find the requisite thickness of a spherical boiler.

RULE.—Multiply the diameter in inches by the pressure on the valve in lbs. per square inch, and divide by

RULES FOR CALCULATING THE STEAM ENGINE.

$\left. \begin{array}{l} 300 \\ 180 \end{array} \right\}$ times the cubic feet of boiler per horse-power, for $\left\{ \begin{array}{l} \text{wrought iron;} \\ \text{copper;} \end{array} \right.$

the result will be the thickness in inches.

Example.—A spherical wrought-iron boiler, 18 feet 8 inches = 224 inches diameter, with 20 cubic feet to each horse-power, and the load on the valve being 8 lbs. per square inch; required its thickness?

20 cubic feet	224 inches
300	8 lbs.
6000	6[000) 1[792
	0.3 of an inch thickness.

6. To find the height of a column of water to supply a boiler against any proposed pressure of steam.

RULE.—Multiply the pressure in lbs. per square inch by 2.44, and the product will express the required height in feet. (145.)

Example.—Required the length of feed-pipe capable of supplying a boiler when the pressure is 5 lbs. per square inch.

2.44

5

12.20

12.2 or 12 feet 3 inches above the surface of the water in the boiler.

SAFETY-VALVE.

7. To find the aperture of a safety-valve, suited to any given pressure.

RULE.—Divide the area of the fire surface by the excess of the pressure above the atmosphere, expressed in lbs. per square inch, and the quotient will be the square of the diameter of the narrowest part of the valve in inches. (146.)

Example.—Required the aperture of a safety-valve for a boiler with 60 feet of fire surface, the pressure being 5 lbs. per square inch above the pressure of the atmosphere?

The feet of fire surface (60) divided by the lbs. per square inch (5) gives 12 for the square of the diameter. Hence, by finding the square root, the diameter of the narrowest aperture of the valve should be 3.46, or about $3\frac{1}{2}$ inches. The aperture should be made rather in excess than defect.

STEAM PASSAGES.

8. To find the diameter of the steam-pipe.

RULE.—Multiply the length of the stroke in feet by the number of strokes per minute, and divide the product by 6; take the square root of the quotient, multiply it by the diameter of the cylinder, and then divide by 20. The result will be the diameter of the pipe in inches. (87.)

Example.—To find the diameter for the steam-pipe of an engine, of which the diameter of the cylinder is 2 feet, the length of stroke 2·5 feet, and the number of strokes per minute 38.

$$\begin{array}{r}
 \text{Length of stroke} \quad 2\cdot5 \\
 \text{Number per minute} \quad 38 \\
 \hline
 200 \\
 75 \\
 \hline
 \text{Divide by 6) } 95\cdot0 \\
 \hline
 16, \text{ nearly} \\
 \hline
 \text{Square root} \quad 4 \\
 \text{Diameter cylinder} \quad 24 \text{ inches} \\
 \hline
 \text{Divide by 20) } 96 \\
 \hline
 4\cdot8 \text{ inches.}
 \end{array}$$

The diameter of the pipe should therefore be about 5 inches.

The same rule applies to the steam passages and the passages to the condenser.

FIRE GRATING.

9. To find the area of the grating.

RULE.—Divide twice the square root of the height, in feet, from the bottom of the ash-pit to the bottom of the chimney by the said height, and multiply the quotient by the number of horse-power. The result will be the area of the grating expressed in square feet. (107.)

Example.—Let the height be 5 feet, and the number of horses' power 96.

$$\begin{array}{r}
 \text{Square root of 5} = 2\cdot28 \\
 2 \\
 \hline
 \text{Divide by 5) } 4\cdot56 \\
 \hline
 0\cdot91 \\
 \text{Horse-power} \quad 96 \\
 \hline
 546 \\
 819 \\
 \hline
 87\cdot36 \text{ square feet for the grating.}
 \end{array}$$

CHIMNEY.

10. To find the area of a chimney for a steam engine.

RULE.—For engines of 10 horse-power and upwards the area of the chimney, in square inches, should be 112 times the horse-power divided by the square root of its height. (149.)

Example.—Required the area of a chimney for an engine of 40 horse-power, the height being 70 feet?

Horse-power	40
	112
Square root of 70 = 8.4	4480.0 (533 inches.
	420
	280
	252
	280
	252
	28

The area should therefore be 533 square inches.

CYLINDER.

11. To find the requisite thickness of a working cylinder.

RULE.—To the diameter of the cylinder in inches add 2.5; multiply the sum by the total pressure of steam in lbs. per square inch in the boiler, and divide the product by 1900. The result will express the thickness for strength; and half an inch may be added for wear.

Example.—A cast-iron cylinder 24 inches diameter is to be made for steam not exceeding 5 lbs. per square inch on the safety-valve; required its thickness?

Diameter	24 inches	Safety-valve	5 lbs.
Add	2.5 „	Atmosphere	14.7 „
	26.5	Total pressure	19.7 „
			26.5
			985
			1182
			394
			19 00) 5 22.05 (0.275 inches
			38 0.5 for wear
			142 0.775 inches, the required
			133 thickness.
			90

PISTON-ROD, &c.

12. To find the diameter of the piston-rod, &c.

RULE.—Multiply the square root of the pressure of the steam per square inch in the boiler by the diameter of the cylinder in inches, and divide the product by

33 for cast iron,
36 „ wrought iron,
57 „ tempered steel;

and the quotient will be the diameter of the rod in inches, for a double-acting engine. For a single-acting engine one-half of the result will be sufficient.

Example.—The force of the steam being 20 lbs. per square inch, and the diameter of the cylinder 38 inches; required the diameter of the piston-rod, the material being wrought iron?

Square root of 20 . . .	4.47
	38
	—
	3576
	1341
	—
36) 169.86 (4.7 inches diameter.	
	144
	—
	258
	252
	—
	6

Thus, for a double-acting engine the diameter should be about 4 $\frac{3}{4}$ inches; and for a single-acting engine 2 $\frac{3}{8}$ inches.

Parallel motion rods should be about half the diameter of the piston-rod; and connecting rods should be about seven-tenths of the diameter of the piston-rod.

THE CONICAL PENDULUM OR GOVERNOR.

The vertical distance between the point of suspension and the plane in which the balls revolve is the height of the governor.

13. To find the height for any proposed number of revolutions per minute.

RULE.—Divide the number 375 by twice the number of revolutions per minute, and the square of the quotient will be the required height of the governor in inches.

Example.—What ought to be the height of the governor, so that the number of revolutions may be 42 per minute?

42	
2	
—	
84) 375 (4.46	
336	4.46
—	4.46
390	—
336	2676
—	1784
540	1784
	—
	19.8916
Height	19.9 inches.

14. The height being known, it is required to find the number of revolutions per minute.

RULE.—Divide 375 by twice the square root of the height in inches, and the quotient will be the number of revolutions per minute.

Example.—Take the same example, and let the height be 19·9 inches, to find the revolutions per minute.

$$\text{Square root of } 19\cdot90 = 4\cdot46$$

2

8·92

8·92) 375·00 (42 revolutions per minute.

3568

1820

1784

36

ECCENTRIC.

15. The length of the levers being given, to find the requisite throw of the eccentric.

RULE.—Multiply the length of the stroke of the valve by the length of the lever on the weight-shaft for the eccentric-rod, and divide the product by the length of the lever which works the valve, and the quotient will be the throw required.

Example.—The stroke of the valve is 5 inches, the lever for working it 10 inches, and the lever for the eccentric-rod 8 inches; required the throw of the eccentric?

Stroke 5

8

10) 40

4 inches throw.

The throw of the eccentric is the distance between the circumferences of the eccentric circle and the shaft, or it is the difference of their diameters.

For calculating the proportions in any other way it will only be necessary to make the throw of the eccentric and the eccentric lever in the same proportion to each other as the stroke of the valve and the valve lever.

PUMPS.

16. To find the number of cubic feet in the volume of a given cylinder.

RULE.—Multiply the square of the diameter in inches by half the length in inches, or 6 times the length in feet; then, cutting off two figures from the right hand, divide the product by 11, and the result will express the required volume in cubic feet.

Example.—What is the volume of a cylinder whose diameter is 36 inches and length 32 inches?

Diameter	36 inches
	36
	216
	108
Square of diameter	1296
Half length	16 inches
	7776
	1296
	11) 207,36
Volume	18.85 cubic feet.

17. To find the power requisite to raise water to any proposed height.

RULE.—Multiply the square of the diameter of the pump in inches by the perpendicular height of the water in feet, and by the velocity also in feet per minute, and, cutting off three figures from the right hand, divide by 96. The result will express the number of horse-power necessary to raise the water.

It is customary to increase the result by a $\frac{1}{5}$ th part, for friction and waste.

Example.—To find the power requisite to raise a column of water 16 inches diameter, 86 feet high, at the velocity of 128 feet per minute.

Diameter	16 inches
	16
	96
	16
	256
Height	86 feet
	1536
	2048
	22016
Velocity	128 feet
	176128
	44032
	22016
	96) 2818 048 (29.35
	192
	898
	864
	340
	288
	524

5.87 one-fifth
35.2 horse-power.

The addition of one-fifth for friction and waste appears to be too much for large engines. We would recommend, as more preferable, to multiply by the velocity increased by 20 feet, and then to make no addition afterwards. The work, in the above example, would stand thus :

$$\begin{array}{r}
 22016 \\
 148 \\
 \hline
 176128 \\
 88064 \\
 22016 \\
 \hline
 96) 3258368 (33.94 \text{ or } 34 \text{ horse-power.} \\
 288 \\
 \hline
 378 \\
 288 \\
 \hline
 903 \\
 864 \\
 \hline
 396
 \end{array}$$

18. To find the velocity necessary to discharge a given quantity of water.

RULE.—Multiply the number of cubic feet discharged per minute by 1100, and divide the product by 6 times the square of the pump's diameter in inches. The result will express the velocity of the discharge in feet per minute.

Example.—The diameter of the pump being 16 inches, and the discharge 179 cubic feet per minute, required the velocity ?

16 inches	179 cubic feet
16	1100
96	1536) 196900 (128 feet velocity per minute.
16	1536
256	4330
6	3072
1536	12580
	12288
	292

19. To find the diameter of the pump necessary to discharge a given quantity of water.

RULE.—Multiply the number of cubic feet to be discharged per minute by 1100, divide the product by 6 times the velocity in feet per minute, and the square root of the quotient will be the diameter of the pump in inches.

Example.—The velocity being 32 strokes per minute, the length of stroke 4 feet, and the discharge 179 cubic feet per minute, required the diameter of the pump ?

32	179
4	1100
128 feet per minute	768) 196900 (256; square root of 256
6	1536 = 16 inches, the
768	4330 required diameter.
	3840
	4900

PARALLEL MOTION.

20. The lengths of the beam, radius bar, and link, as in fig. 4, Plate X. (B) being given, together with the length of the stroke, to find the point E in the link where the piston-rod must be attached.

RULE.—Divide the lengths of the beam and radius bar, measured from their centres of motion, by half the length of the stroke. From the square of each of the two quotients subtract *unity*; find the square roots of the remainders, and subtract them respectively from the preceding quotients. The numbers so deduced will express the relative proportion between the segments of the link; and if we multiply each of them by the length of the link and divide the product by the sum of the two numbers, we shall get the respective distances of the required point from the beam and radius bar.

Example.—The radius of the beam is 7 feet, the length of the radius bar 4 feet, the link 2 feet, and the length of the stroke 5 feet; required the point of connexion of the piston-rod?

Half-length of stroke = 2.5 feet.			
2.5) 7.0 (2.8	2.5) 4.0 (1.6		
5.0	25		
200	150		
200	150		
Quotients 2.8	1.6		
2.8	1.6		
224	96		
56	16		
Squares 7.84	2.56		
Subtract 1	1		
6.84	1.56		
Square roots 2.6153	1.2490	Numbers {	.1847
Subtracted from quotients .1847	.3510		.3510
		Sum	.5357

$$\begin{array}{r}
 \cdot 1847 \\
 \text{Link } 2 \\
 \hline
 \cdot 5357) \cdot 36940 (0 \cdot 69 \\
 \underline{\cdot 32142} \\
 47980 \\
 \cdot 3510 \\
 \text{Link } 2 \\
 \hline
 \cdot 5357) 7020 (1 \cdot 31 \\
 \underline{5357} \\
 16630 \\
 \underline{16071} \\
 5590
 \end{array}$$

The distance of the required point from the end of the beam is therefore 0·69 feet, or 8·28 inches, and the distance from the end of the radius bar is 1·31 foot or 1 foot 3·72 inches. N.B. As a check against any gross blunder, the distances multiplied by the respective lengths of the beam and radius bar ought to give nearly equal results. In the present case they give 4·83 and 5·24. For short strokes, however, they ought to come much nearer.

21. To find the length of the radius bar.

I. When the radius bar and piston-rod are attached to the links at the same distance from the beam.

RULE.—First, from the radius of the beam, divided by twice the length of the parallel bar, subtract *unity*.

Secondly, Find the square root of the difference between the square of the radius of the beam and the square of the half-length of the stroke, and add this root to the radius of the beam.

Thirdly, Multiply together the numbers so found, and the product, added to the length of the parallel bar, will give the length of the radius bar.

Example.—Let the radius of the beam be 11 feet, the length of stroke 5, and the length of the parallel bar 4 feet.

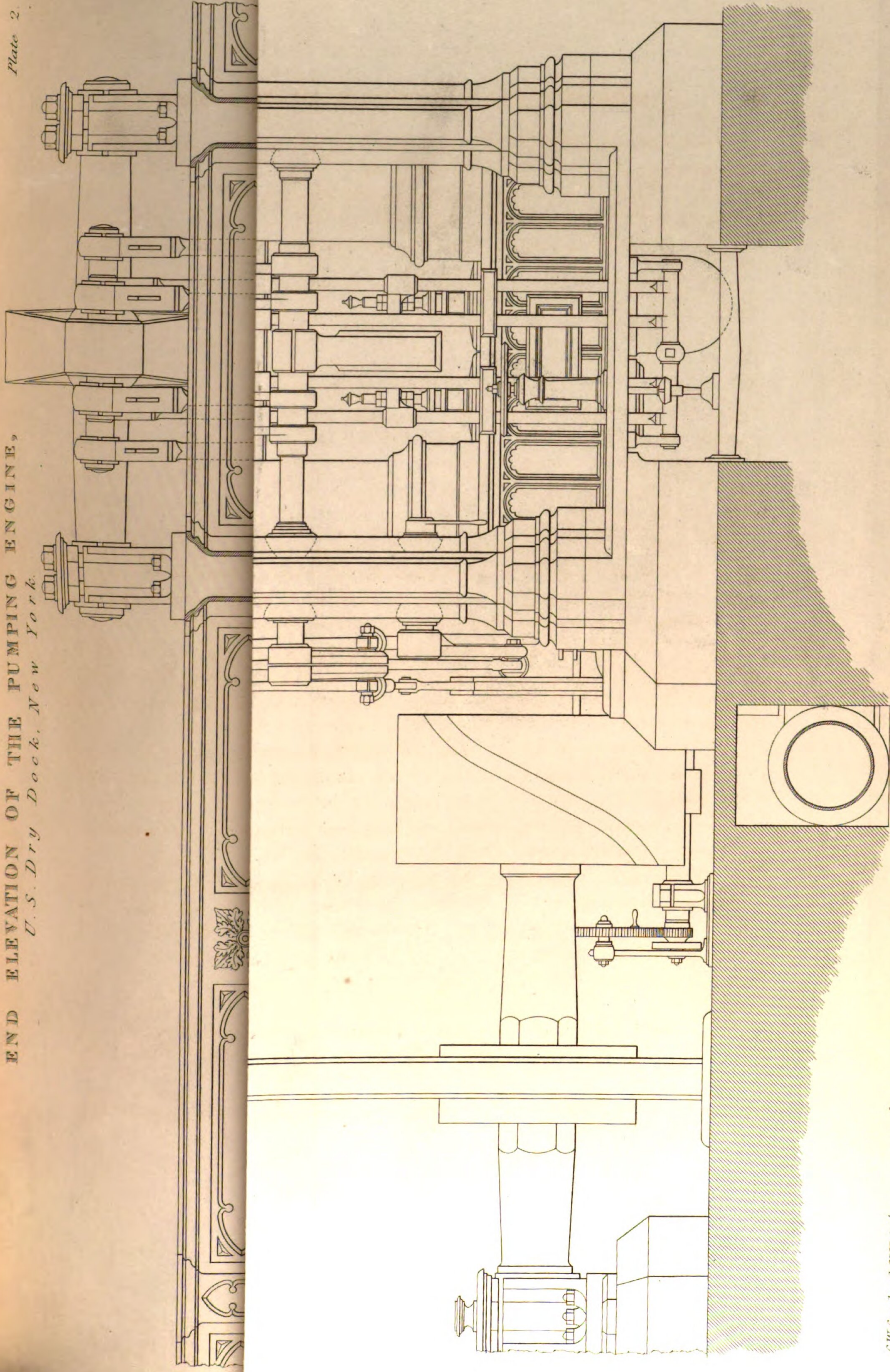
First operation.

$$\begin{array}{r}
 \text{Parallel bar } 4 \text{ feet} \quad 8) 11 \\
 \underline{2} \\
 8 \quad \text{Subtract } 1 \\
 \hline
 \cdot 375^1
 \end{array}$$

¹ This difference may sometimes be negative; in that case the final product must be subtracted from the length of the parallel bar. (See next Example.)

END ELEVATION OF THE PUMPING ENGINE,
U.S. Dry Dock, New York.

Plate 2.



C.W. Copeland, N.Y. del^t

London: John Weale, 1851

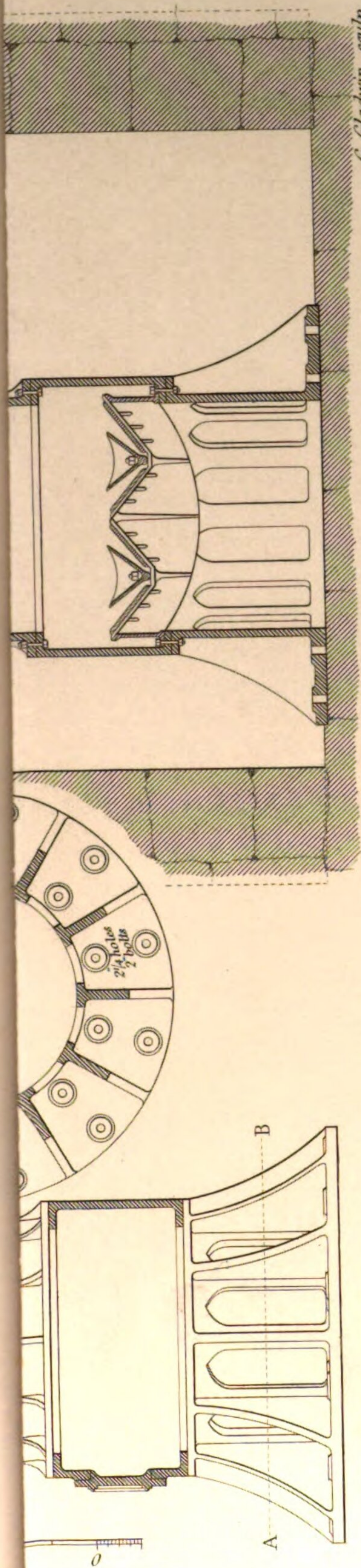
15 feet

10

5

0

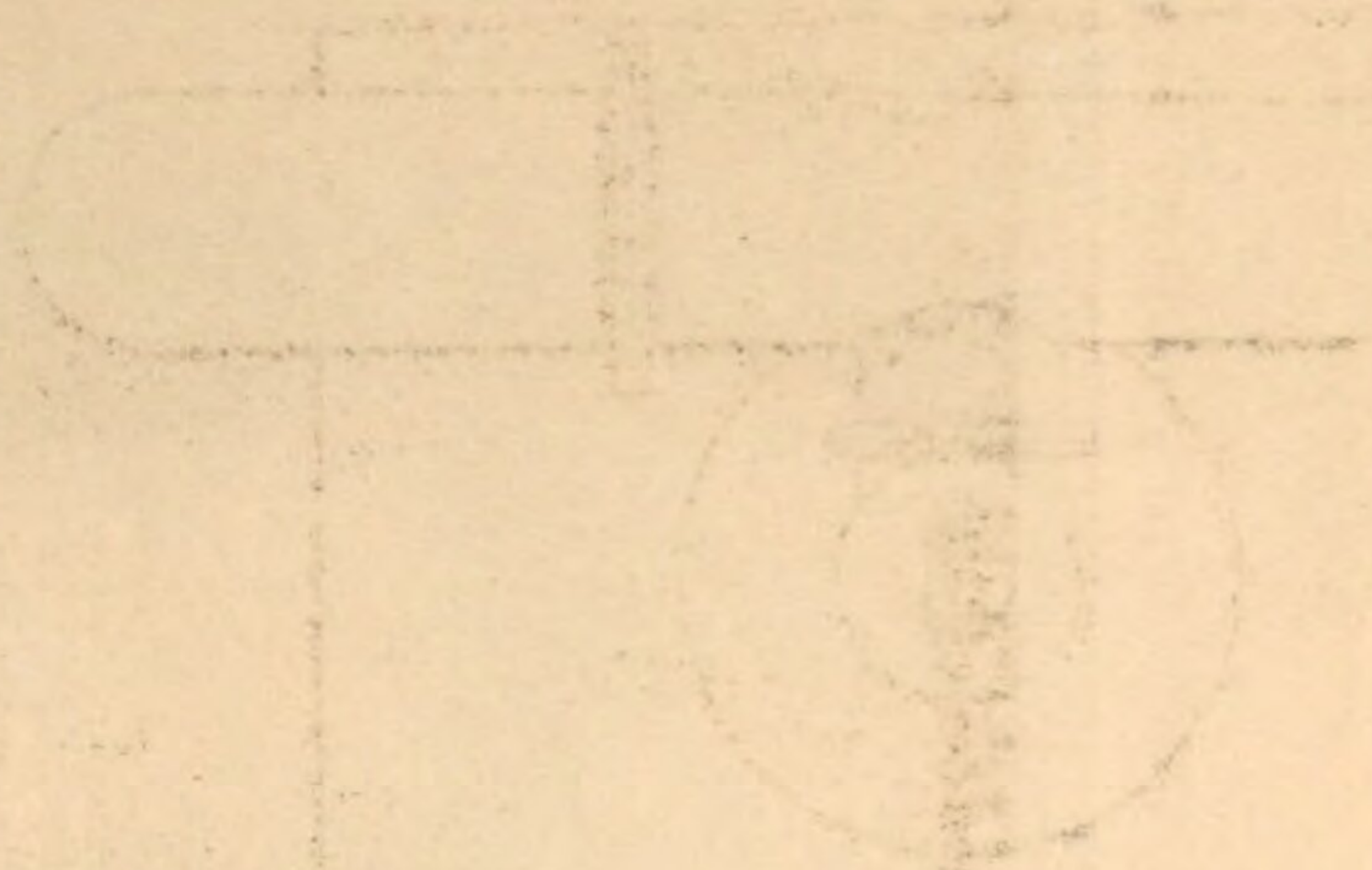
G. Gladwin, sculp.

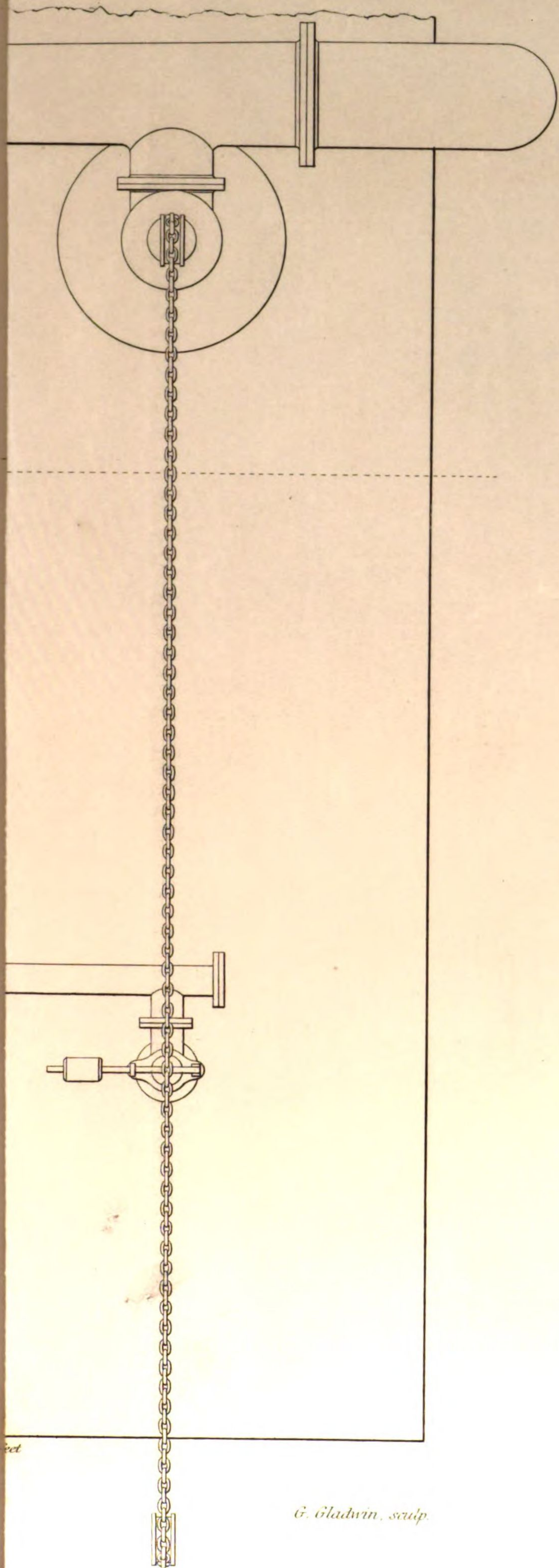


C. W. Copeland, N.Y. del^t

London: John Weale, 1851.

G. Gladwin, sculp.

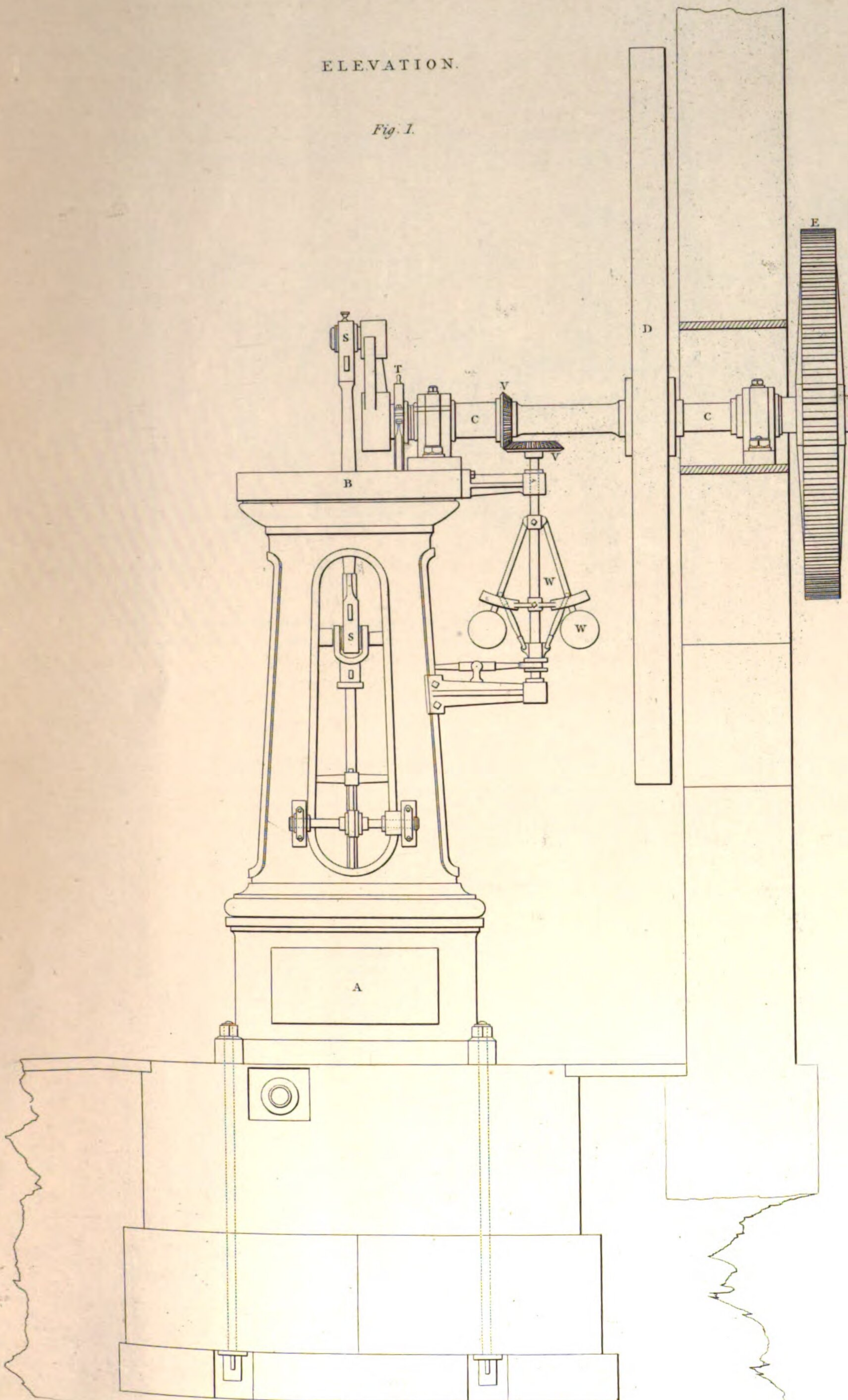


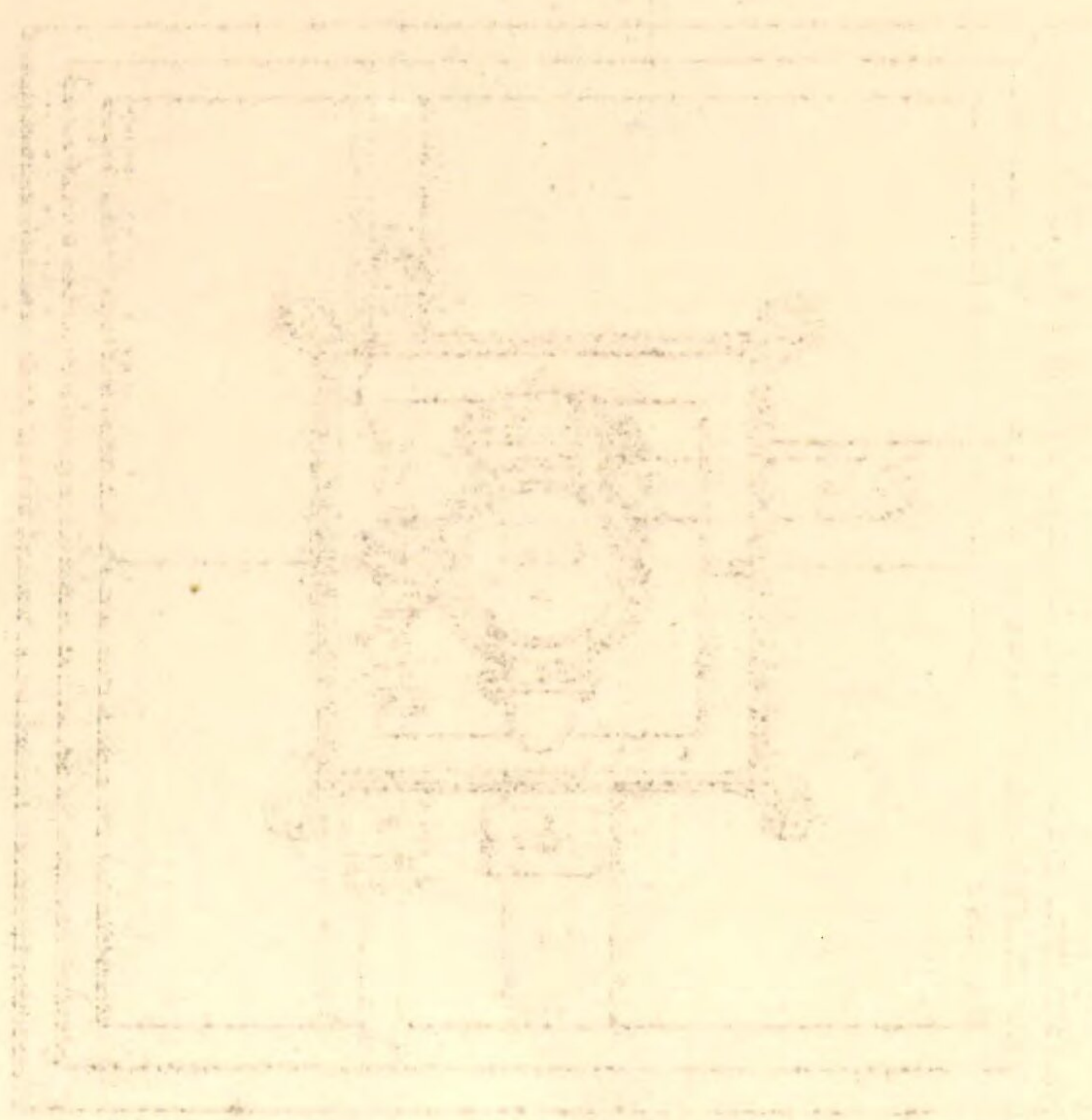
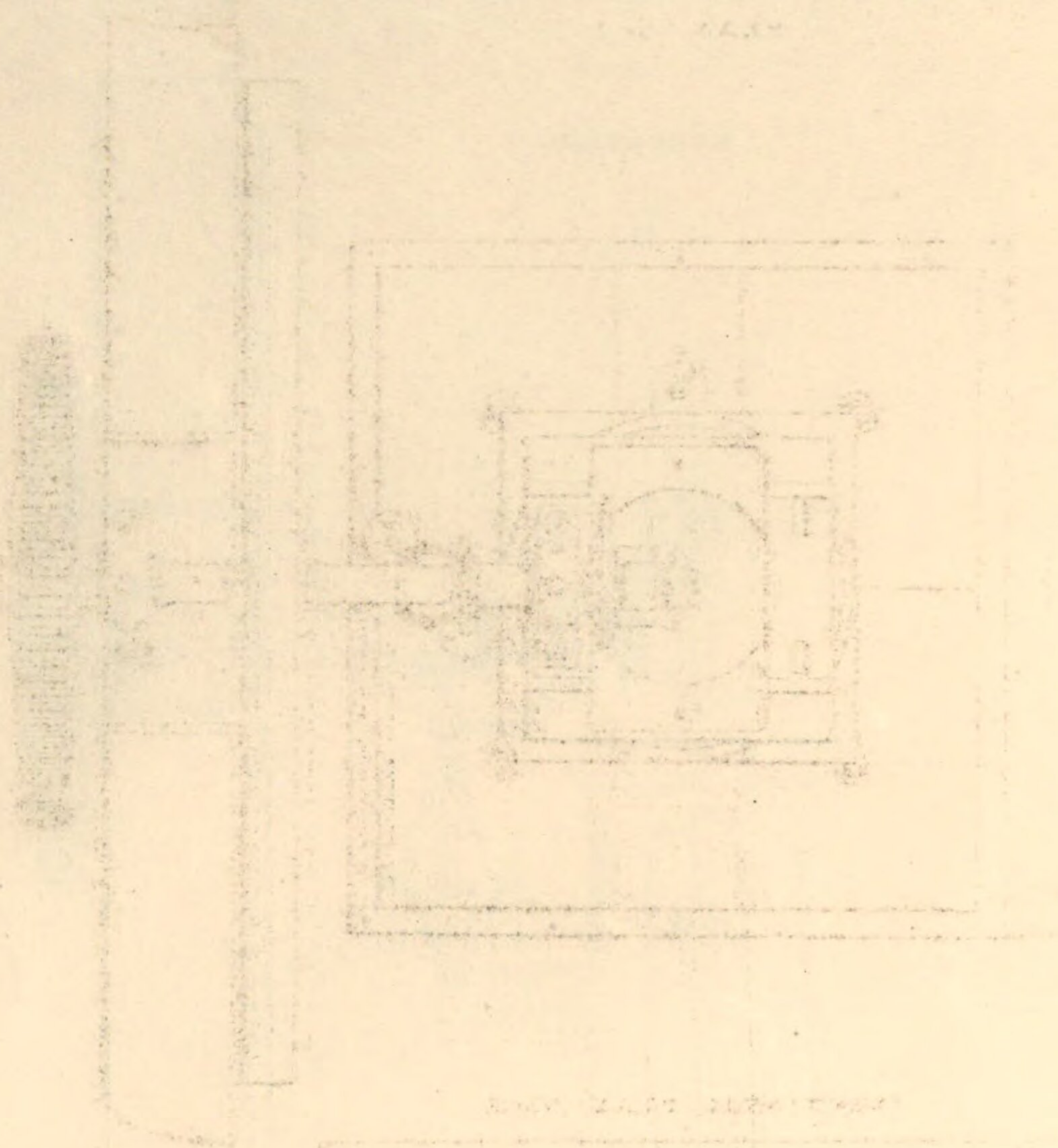


TEN HORSE POWER STEAM ENGINE, AS CONSTRUCTED BY WILLIAM FAIRBAIRN & CO.

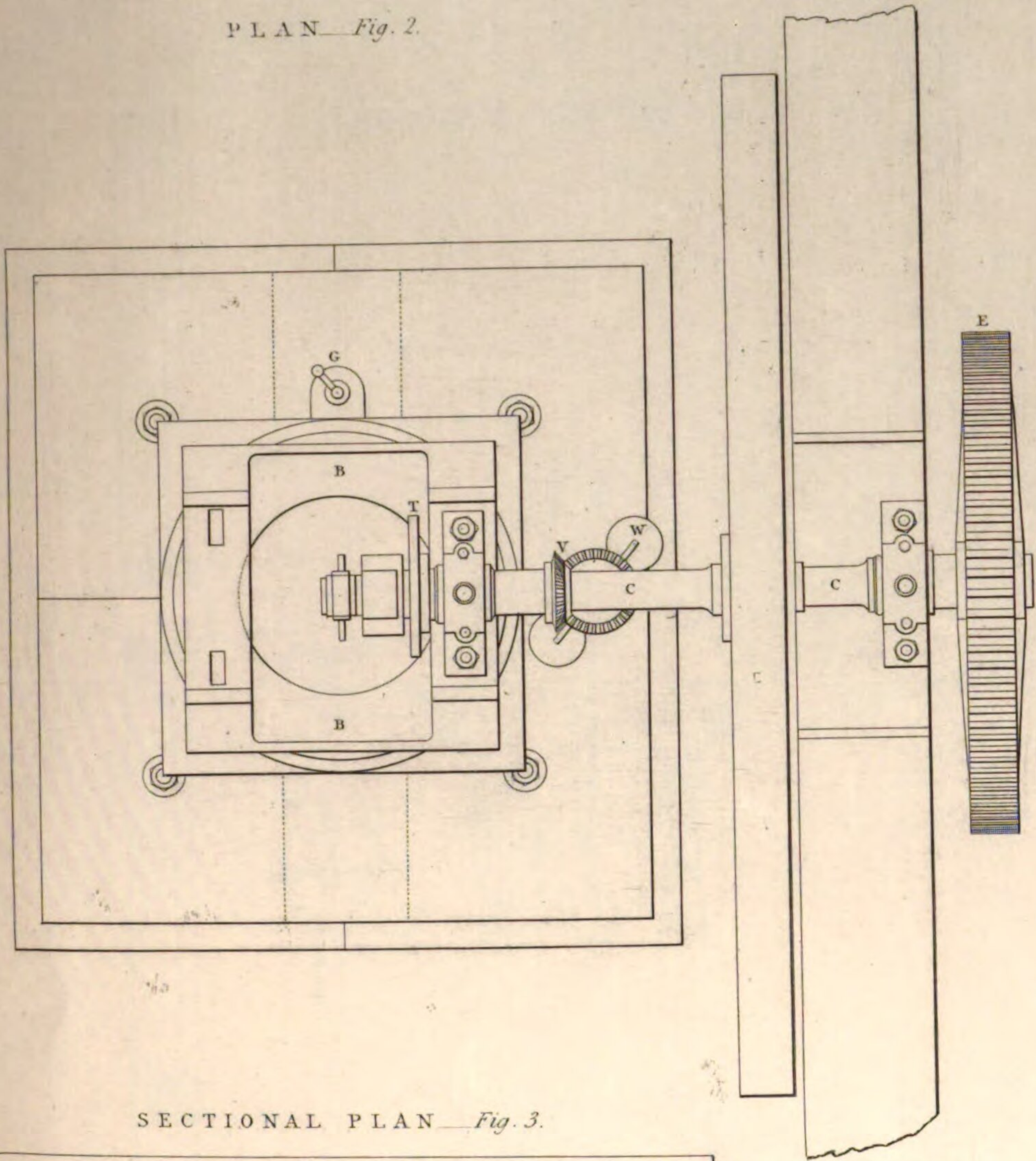
ELEVATION.

Fig. 1.

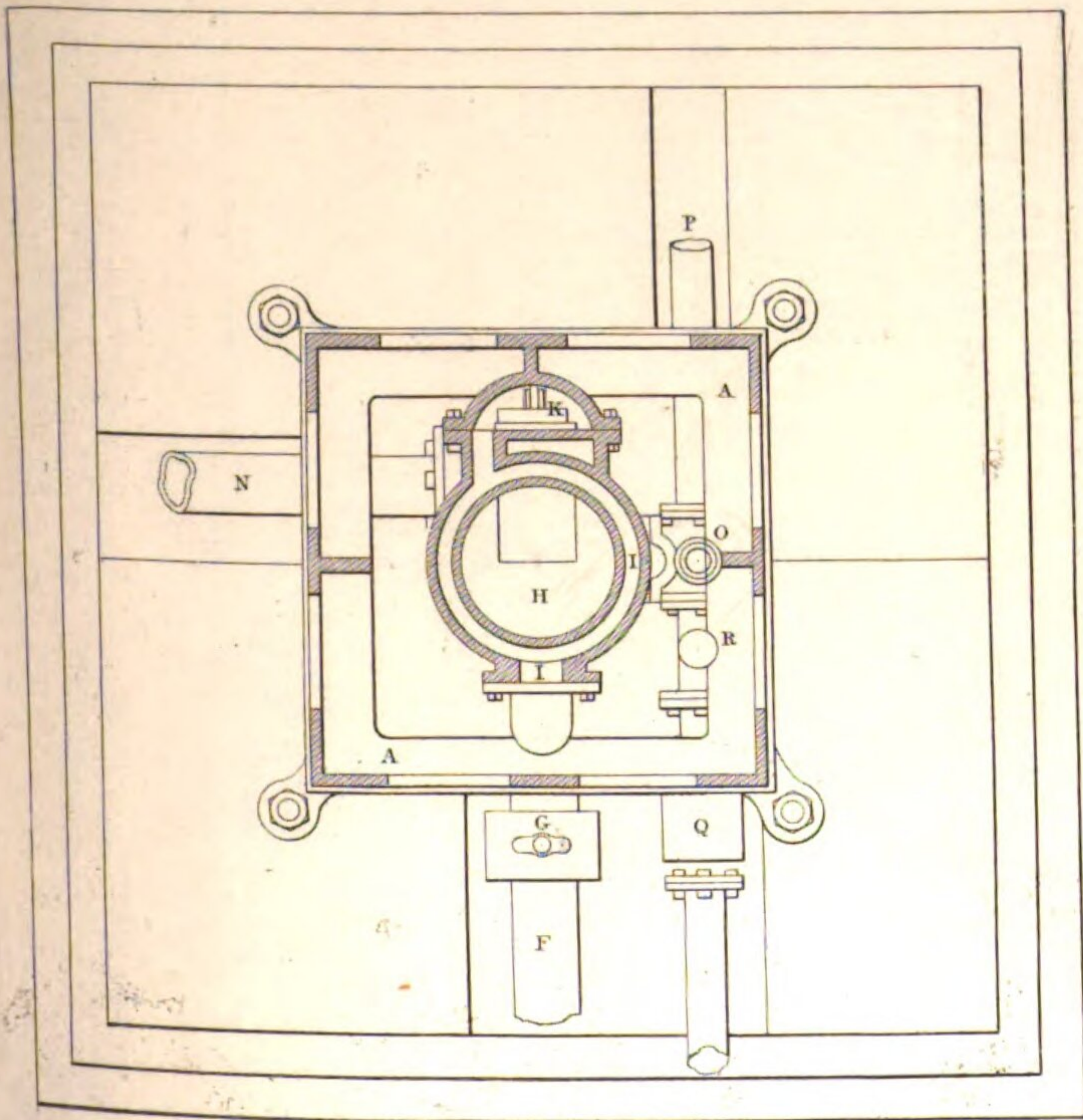




PLAN Fig. 2.

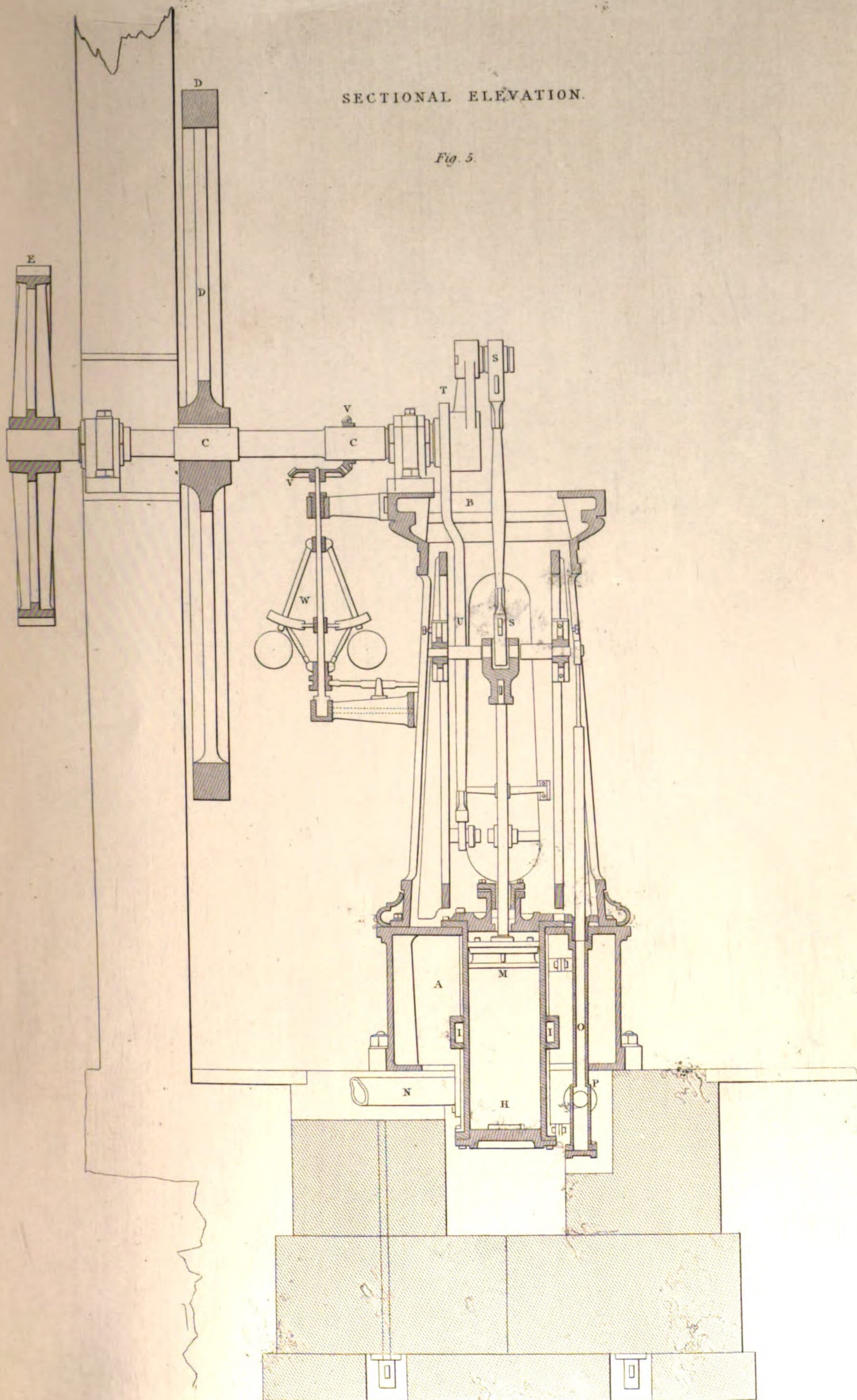


SECTIONAL PLAN Fig. 3.



SECTIONAL ELEVATION.

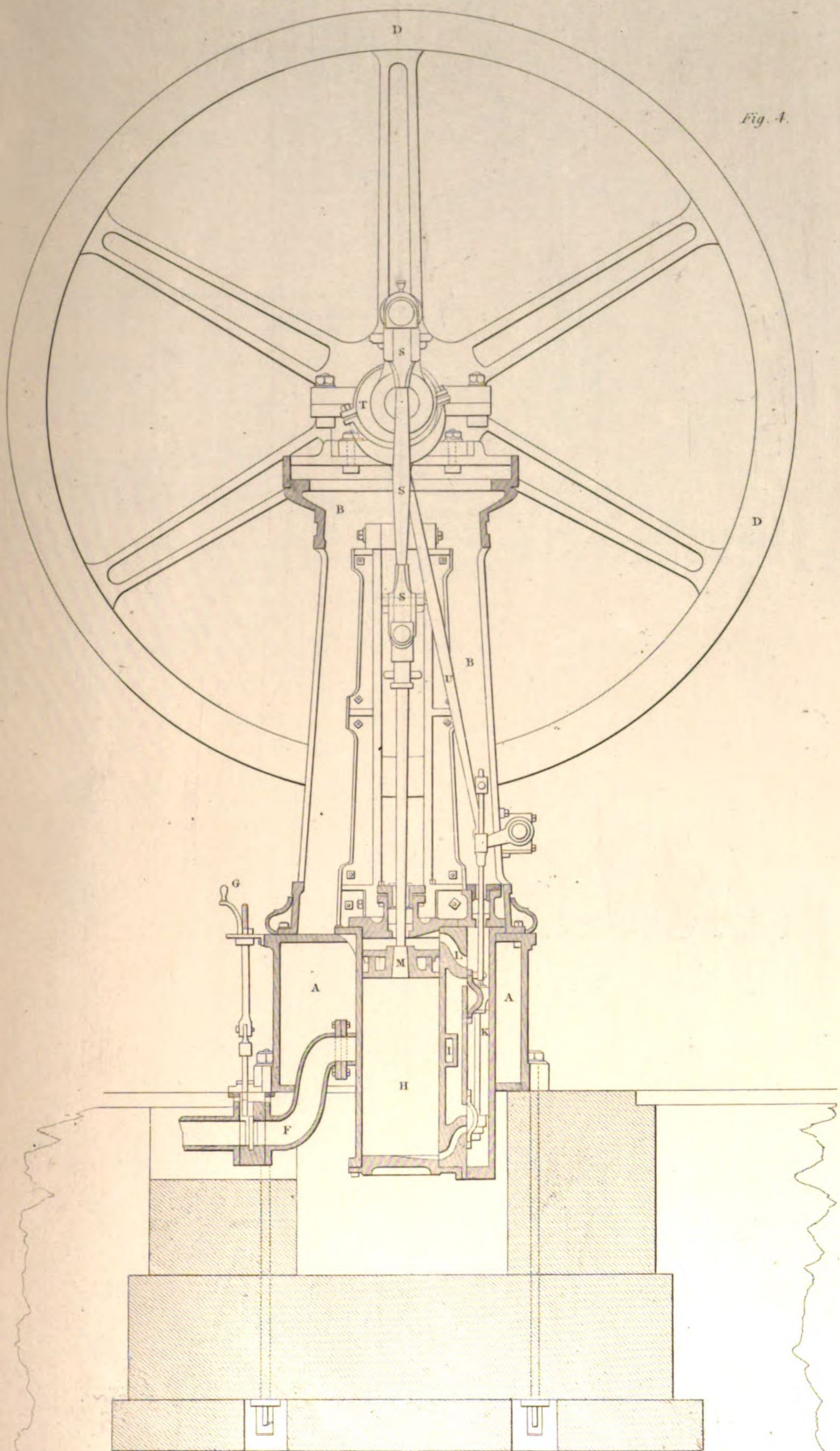
Fig. 5.



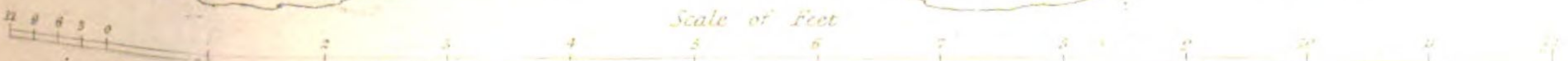
CROSS-SECTIONAL ELEVATION.

PLATE 4.

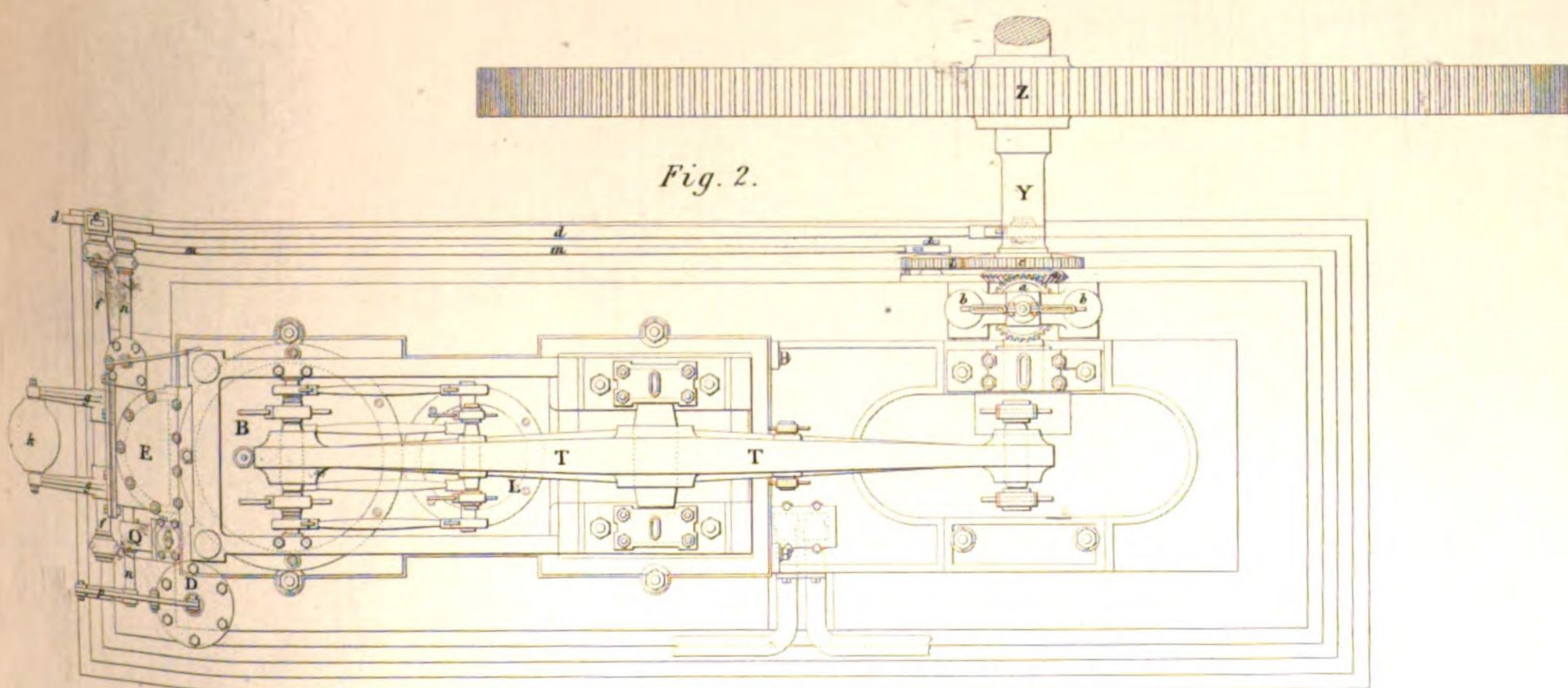
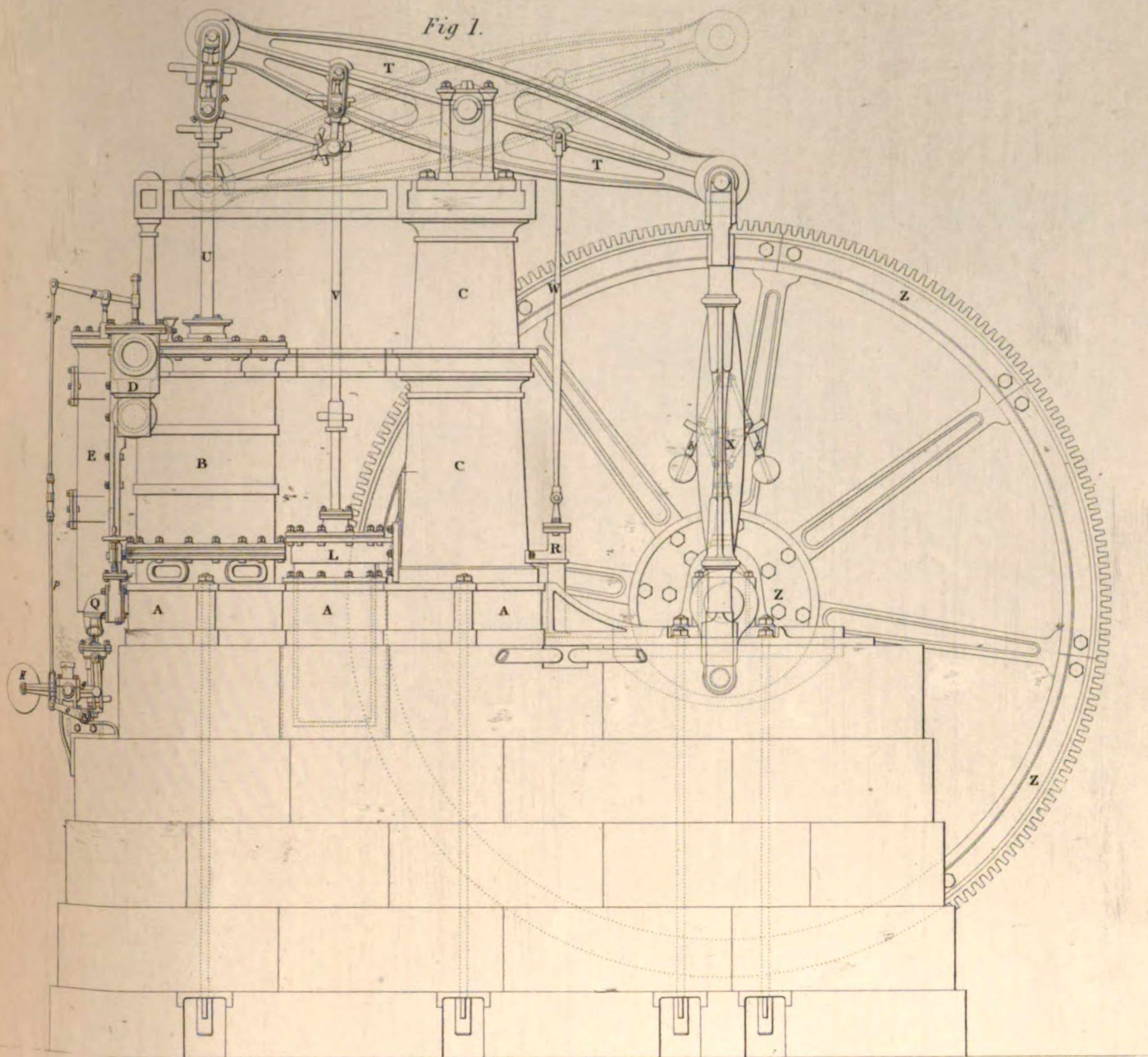
Fig. 4.



Scale of Feet



J. Bellin sc.



Scale of Feet
22 9 6 3 0 5 10 15

FRONT ELEVATION

BACK ELEVATION

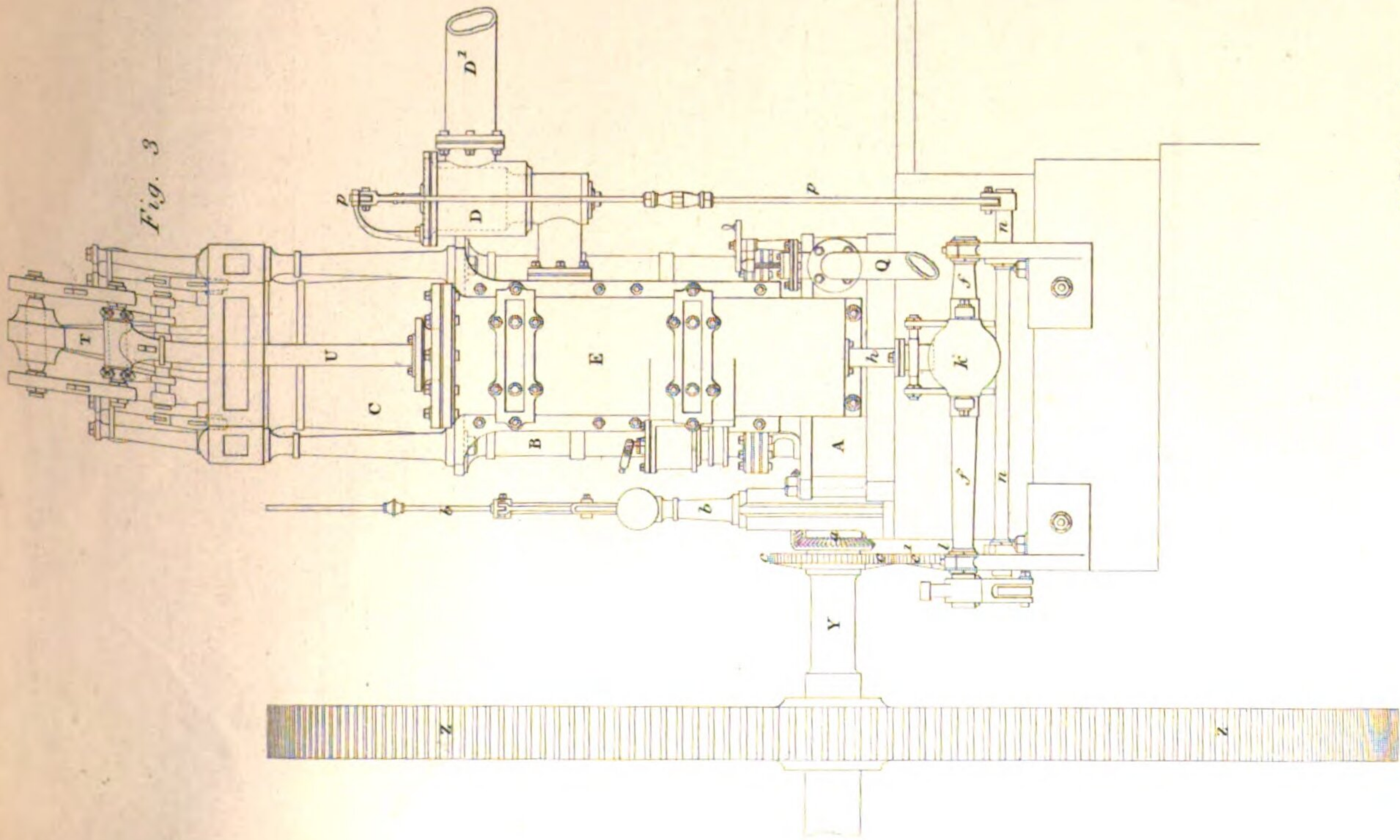


Fig. 3

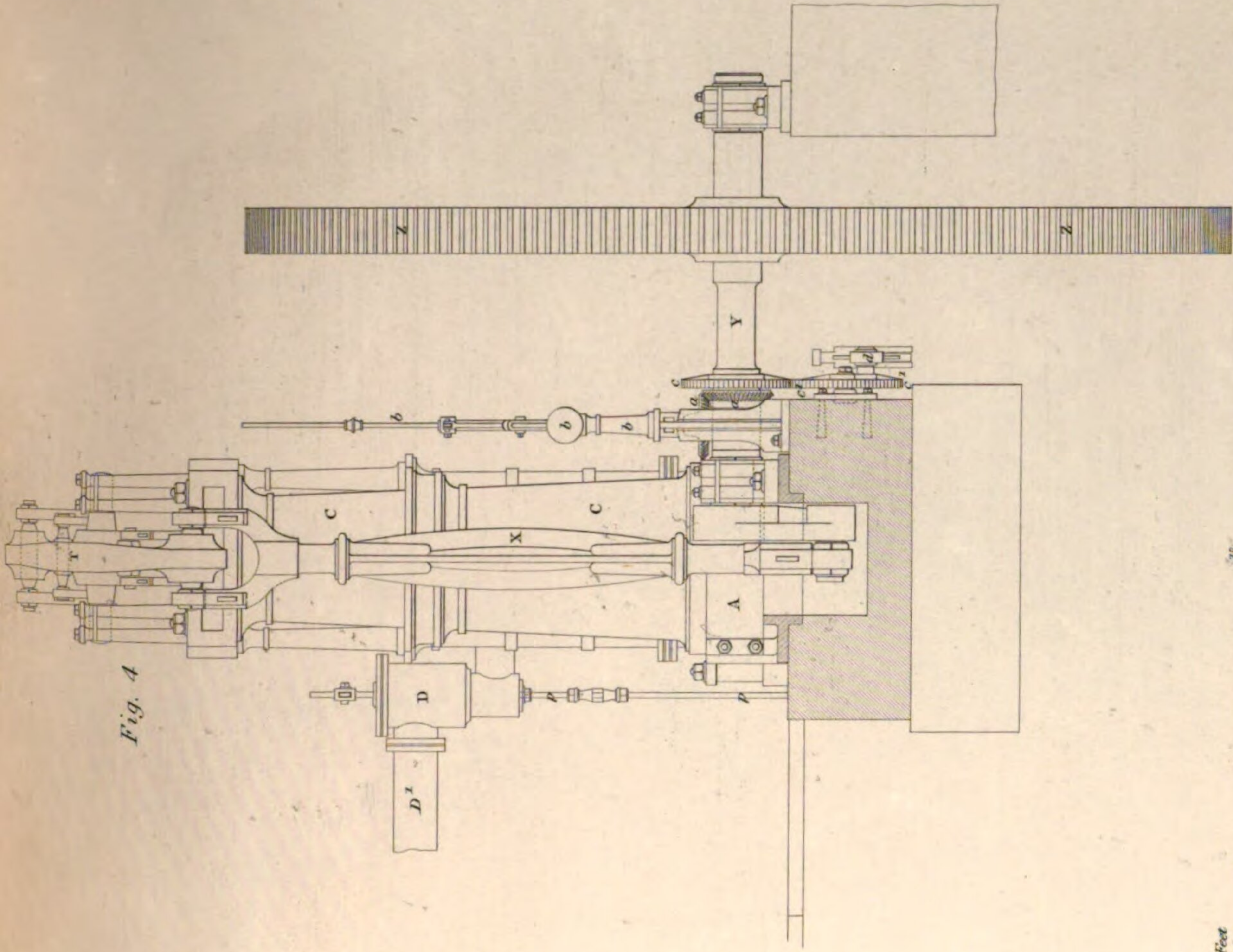
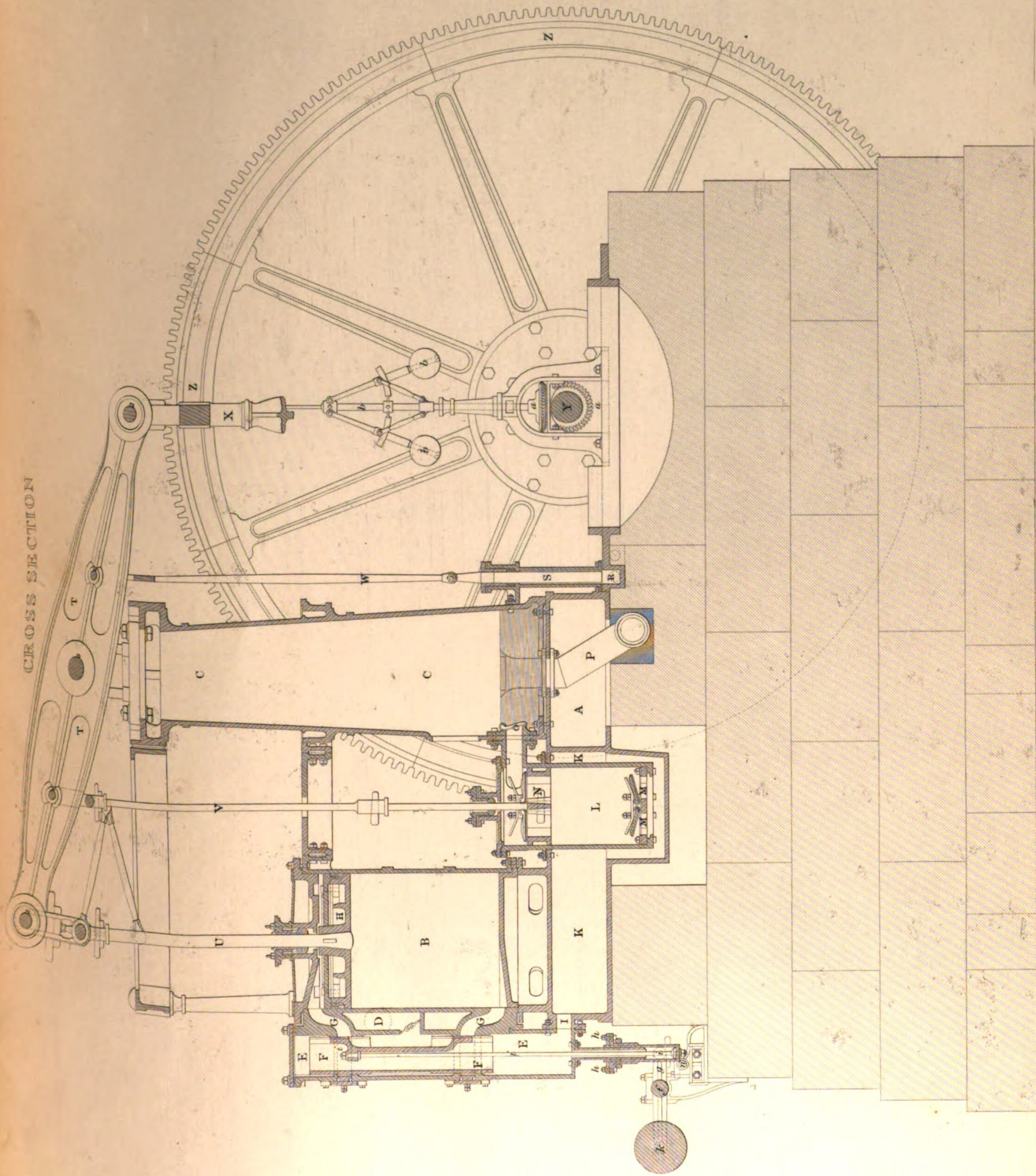


Fig. 4

Scale of Feet
0 1 2 3 4 5 6 7 8 9 10

CROSS SECTION



25 Feet

12 9 6 3 0

John W. White Architectural Library, 30 High Holborn

W. A. Raper del. et sc.

REFERENCES TO THE ARTICLES IN WHICH THE CONSTRUCTION IS
INVESTIGATED.

PLATE I.

Fig. 1 is an isometrical projection of a rectangular steam boiler (arts. 170, 171), with part of the top plates of the boiler, and part of the brickwork removed to show the internal parts. A is the boiler; the half of the doorway to the fire is at B, and the fuel rests on the fire-bars G, and against the back F: the flame passes over F, and along under the bottom; it rises at H, and returns in a flue by the nearest side, passes round the end by the flue I, and along a flue by the further side to the chimney at L; a horizontal damper K regulates the aperture to the chimney. (See art. 202.) The door to the ash-pit C should shut perfectly close, and the supply of air for the fire should enter by a passage E, the aperture of which is regulated by the force of the steam acting by the chain *n n* (art. 203). In the figure the air is supposed to enter by the grating at D. The supply of water enters by the pipe M N, the end N being turned along the bottom of the boiler, that the water may acquire heat before it mixes with the rest; the admission is regulated by the stone float *c* (arts. 196–198). The steam passes to the engine by the pipe S, and when it is not required, it goes off by the safety-valve V (art. 205), and through the pipes T W. The internal valve is on the man-hole plate at *a b* (art. 204). The steam-gauge is at *h* (art. 503), the gauge-cocks at *k i*; and a cock to clear the boiler of water is at R. Opposite each flue, as at Q, there must be an aperture to clear it out at. (See art. 151, and p. 118, note.)

Fig. 2 shows a method of admitting water to a boiler where high-pressure steam is used. The pump forces the water by the pipe D, through the valve aperture A, into the boiler; but when the quantity is in excess, the copper float F closes the valve, and opens the valve B to the waste-pipe C, by which the surplus passes off. The parts must be balanced on the axis by the weight G. (See art. 198.)

Figs. 3, 4, 5, and 6 are tops for engine chimneys. Fig. 3 is a plain obelisk: the proportions of an Egyptian obelisk are very well adapted for a chimney, and if the faces were stuccoed and covered with sunk figures, it would render them novel and ornamental. Fig. 4 is an octagon top for a square shaft; Fig. 5 an octagon chimney; and Fig. 6 a chimney to represent a column. (See arts. 219–223; also art. 220, and p. 150, note.)

PLATE II.

This Plate represents a plan and two sections of a cylindrical steam boiler (arts. 172–175). Fig. 1 is a cross section, Fig. 2 a longitudinal section, and Fig. 3 the plan; in the last, half of it is the plan above the level of the boiler bottom, and the other half below it. The fuel is put in at the fire-door B, it inflames at D, and the smoke in passing over the hot current of air rising through the red fuel at E is consumed. The ash-pit door is supposed to be provided with a register to regulate the admission of air, but it would be better to make it regulate itself as in the preceding Plate. By pushing back the plate *k* by the handle *i*, the clinkers are let out behind (art. 193). The supply of water is regulated by a hollow copper-ball float, and the supply is continuous, except, when by the water rising, the valve is closed (art. 199). To prevent sediment depositing over the fire, I would recommend a division to be placed across the boiler as at O; the safety-pipe T W is recommended instead of the valve, on account of the certainty of its action. The first effect of strong steam is to displace the water down to the level of the mouth of the pipe at T; this sets

the feed-pipe into action, and steam and water rise by the pipe T W till the boiler be cooled to its proper temperature (art. 209); no internal valve is required: S is the steam-pipe leading to the engine. The same letters refer to the same parts in all the figures. For the area of the grate and ash-pit, see arts. 142-144; size of the boiler, art. 174; the area of the chimney, arts. 219-223; and the strength of the boiler, arts. 467, 470, 478 and note.

Note.—In Section II. I neglected to remark that the boilers formed of small pipes cannot possibly produce more effect than others, and that every boiler must contain a certain quantity of water and steam, otherwise the slightest neglect of the fire would cause the engine to stop. It has been pretty clearly ascertained that not one of the combinations hitherto proposed has equalled the kind of boiler above described. (See art. 166, and p. 125, note.)

PLATE III.

This Plate represents Brunton's apparatus for feeding furnace-fires by means of machinery. The general principles of the method and its advantages have been stated (art. 195), and it only remains to describe the parts of the figure. The apparatus was added to two boilers of Boulton and Watt's construction. To the original boilers A A, two additional boilers B B are attached, which are prepared for the purpose of being over the revolving fire-grate; the smoke from which passes over and under the bridges *d d*, and round the boilers A A, by the flue C; and D D are the flue-doors. The coals, broken to a proper size, are put into the hoppers E E, and fall through the openings F F, and through the top of the boiler to the grate. The door H, to examine or repair the fire-place, is attached to the boiler by a cement joint. The additional boilers are connected to the main boilers by the steam-pipes G G.

To clear away the dust that falls over the edge of the revolving grate, there are doors at I I; they also admit a small quantity of air to the burning fuel. The axis K of the grate is turned by the pinion and wheel at L, turned by the upright shaft N, which receives its motion by the shaft R from the engine.

The pivot of the shaft N, and of the spindle K, are in the foundation plate M. The grate-bars are surrounded by fire-bricks *h*, and a thin hoop projects below the frame, and moves in sand in a trough *f*, and prevents air entering by any other passage than through between the bars: a scraper attached to the grate, and consequently moving with it, keeps the channel *i* clear of dust.

To regulate the fire, the chains S S are connected to the damper chains, and raise or depress the wedge U by the lever T, and thus increase or diminish the supply of coals according to the force of the steam. (See art. 202.)

The feed-pipe O, with its stone float *c* and balance *l*, are as in other boilers (art. 196). The gauge-cocks are at Z, the man-hole at *a*, with an internal valve at *b*; the safety-valve is at V, with a pipe Q to convey away the steam; P is the pipe for conveying steam to the engine, with a self-acting stop-valve W, to prevent the steam passing from one boiler to the other when both are in action; and X Y is a lever handle for closing the aperture when only a small supply of steam is required.

The construction will admit of considerable variation; and its advantages in saving fuel, in regularity of action, and in consuming the sooty matter of smoke, render it a desirable addition to a large boiler. (See arts. 194, 195, 512, and p. 295, note.)

PLATE IV.

Fig. 1 is a section of the parts of a high-pressure engine with a four-passaged cock. The engine is supposed to be partly within the boiler, of which DB is the top plate. P is the steam piston, and R the piston-rod; A is the four-passaged cock; the steam enters from the boiler at S, and passes through *t* to the top of the piston, and the steam below escapes through the passage *b*, and pipe *a* and E, to the atmosphere; the pipe E is surrounded by water, which the escaping steam warms ready for the boiler. By turning the cock the motions are reversed, but it is obvious we cannot in this engine employ the expanding force of the steam. The motion is regulated by a throttle-valve V. (See arts. 301-306.)

Figs. 2 and 3 show a section and plan of a similar engine, with a D-slide instead of a cock; the steam enters from the boiler at S, and by the passages being shut and opened close to the extremities of the cylinder, there is no loss by the communicating pipes being filled with strong steam. (See art. 309.) This engine will not work expansively unless the construction of the slide be altered. (See art. 316.) Contrary to the usual practice, the packing of the slide is on the sliding part; the advantage of this plan is obvious, but the practical difficulty of boring a semi-cylinder is incurred.

Fig. 4 is a simple arrangement of the high-pressure engine by which the expanding power of the steam may be used; it is the invention of Murdoch. The passages are opened and closed by pistons sliding in a pipe: the steam enters this pipe at S, and the steam is supposed to be just shut off by the upper piston, so that by the expansion of that in the cylinder the rest of the stroke is completed, the passage E to the atmosphere being still open. (See arts. 316-325.) The slide would be improved by making it of the form of a D-slide.

The construction of the pistons of the slide is a suggestion which may perhaps answer better than the common ones (art. 395, and note).

Fig. 5 is an arrangement to illustrate the action of a high-pressure engine to work expansively by means of combined cylinders. (See arts. 326-328, and notes.)

PLATE V.

Fig. 1 is a section of a double-acting condensing engine, with a slide adapted for working by the expanding force of steam; the slide being, in fig. 1, in the position for letting the steam on at the top. Fig. 2 shows the steam shut off, and the passage to the condenser still open; and Fig. 3 the position when the steam is let on at the bottom. (See art. 393.) The steam enters at S, and a pipe of communication between the steam-pipe and the condenser is necessary, to allow steam to enter the condenser when the engine is about to be set to work (art. 359).

Fig. 4 is a section of a single-acting condensing engine, with valves to the passages (see art. 351); and Fig. 5 a different arrangement of the valves for a single engine.

Fig. 6 represents the box slide, admitting steam through the upper passage and open below to the eduction passage, or to the condenser.

In all these figures the same letters indicate the same parts. C is the steam cylinder, P the steam piston, R the piston-rod, B the condenser, with a jet of water playing into it from I, the injection cock; A is the air-pump, and *p* its piston; G is the foot-valve between the condenser and air-pump; M the air-pump, and Q the discharge-valve of the air-pump, through which the air and

hot water are forced into the hot well K, from whence a part is raised by a small force-pump to the boiler-feed head, and the rest runs off by a waste-pipe. H is the blow-valve to the condenser (art. 511). The condenser and air-pump are placed in a cistern, which is constantly supplied with cold water by a pipe N.

The jet should be made through a rose on the end of the pipe; for, to produce speedy and perfect condensation, the cold fluid should present the greatest possible surface to the steam it is to condense (see art. 225); and it should be impelled into the condenser with greater force than the ordinary head in the cistern admits of.

In large engines the connecting eduction pipe E, fig. 1, may be on the outside of the steam-pipe S, and the parts of the slide connected only by a rod, as mentioned in art. 392.

PLATE VI.

Fig. 1 is a section of a common atmospheric steam engine; C is the cylinder, and the piston is supposed to have a wooden bottom, according to the practice of Smeaton (art. 411); the steam is let on by a modification of Hornblower's valve (art. 386), instead of the common regulator (art. 406). For the proportions of the engine, see arts. 338-344.

Fig. 2 is a section of an atmospheric engine with a separate condenser and air-pump (see arts. 345-350). An elevation of this engine is shown in Plate XII.

Fig. 3 is a section of a combined cylinder engine on Hornblower's principle, where the steam passages are opened and closed by a combination of slides in one pipe. (See arts. 370-374.) Woolf's engines have two cylinders, but the passages are opened by valves.

Fig. 4 is a section of Hornblower's double-seated valve. (See art. 386.)

Fig. 5 represents a section of Murray's slide; it is a sliding cover which alternately covers the passages *ac* and *cb*: the disadvantage of this construction is, that the pressure of the steam is nearly three times as great, on the moving surfaces, as it is in Murdoch's arrangement shown in the last Plate. (See art. 391.)

Figs. 6 and 7 show the mode of forming the apertures of a four-passaged cock, so that the steam may be shut off at any period of the stroke without closing the passages to the condenser. (See art. 401.) T is the passage to the top, and B that to the bottom of the cylinder; the steam enters at S, and C is the passage to the condenser. Fig. 6 shows the position of the cock when the steam is entering, and Fig. 7 when it is shut off.

PLATE VII.

This Plate is to represent the construction of pistons.

Fig. 1 represents a section and part of the plan of the common packed piston, which is tightened by the screws S when it wears. (See art. 412.)

Fig. 2 shows one of Woolf's methods of tightening the whole of the screws at once, and consequently in the most regular manner, without having to take off the cylinder lid. (See art. 413.)

Fig. 3 is the plan and section of Cartwright's metallic piston, as at first executed; it was afterwards made with spiral and other springs, acting only on the interior segments of rings *bb*, but it required that the outer ones should be moved; and this has been done by making the interior segments in short pieces to cover the joints of the outer ones, so as to leave space to insert springs between

them, to act directly on the outer segments, by Mr. Lloyd: it has also been done by inserting a short cylindrical piece against each joint of the outer ring, both the cylindrical pieces and the outer segments being pressed outwards by spiral springs: this method is employed by Messrs. Hall. (See art. 414.)

Fig. 4 represents Barton's construction of metallic pistons in plan and section. The points of the wedges *G* expand faster than the segments *E* in the ratio of *mn* to *on*, and hence wear the cylinder unequally. To prevent this, the points are shortened, and two elastic hoops *bb*, fig. 5, are put round, neatly fitted with a loose tongue joint, as shown at fig. 6. (See art. 415.)

Fig. 7 shows a method of avoiding the defect of Barton's piston, by keeping the points of the wedges as much within the segments of the piston as may be necessary for wear, before a change of parts becomes necessary, and making two series to break joints. (See arts. 416, 417.)

Fig. 8 represents a section of Jessop's piston; and Fig. 9 the expanding coil of metal which rubs against the cylinder. (See art. 418.) I am of opinion that a more perfect method of pressing the packing against the metal coil is the only thing wanted to render this decidedly the best kind of piston.

The friction of pistons is investigated in art. 419.

PLATE VIII.

Fig. 1 represents a section of the steam-pipes and valves of Messrs. Fenton and Murray's¹ double engine (Plate XV.), and Fig. 2, the communicating rods. The steam enters by the pipe *C*, which has a throttle-valve at *a*, to regulate the supply of steam to the engine (art. 489). It is regulated by the action of the governor-balls on the lever *b*, by the connecting rod *c*: the rotary motion is communicated to the axis of the governor by means of a band passing from a pulley on the crank-shaft to a similar pulley *d* on the axis of the governor. The governor consists of two bent levers *ee*, passing through a slit in the middle of the spindle, and turning upon an axis at *f*. The upper part of the spindle has a slide *h*, which is connected to the levers by the rods *ii*, and ascends when the centrifugal force of the governor increases, so as to cause the balls to rise, and descends when it decreases; and the lever *l* moves with it, and consequently the valve. When the engine is at rest, the balls *jj* rest against the arms *kk*; the upper end of the levers *ee* are nearer to each other, and the rod *c* is raised so that the throttle-valve may be quite in a horizontal direction, and the pipe completely open for the passages of the steam. (See art. 495.)

By the pipe *DD* the steam passes either to the top or bottom of the cylinder from the throttle-valve *a*, and by the eduction pipe *EE* the steam from either passes down to the condenser. The valves *no* have each a cylindrical tube or spindle passing through the stuffing-boxes *rs*: the upper end of each of these has a stuffing-box, the upper one at *t*, the other at *u*, for the rods of the valves *p q*, which open to the eduction pipe *E*, so that either the steam or eduction valves may be opened without allowing steam to escape.

Fig. 2 is a front view of the two sliding-rods which give motion to the valves *no p* and *q*: these rods are kept in a perpendicular direction by the pieces *zz* and the guide *l*; the lower ends of the rods have friction-rollers *3 3*, which are acted upon by the two eccentric pieces *4 4*, on the horizontal shaft *Z*, which derives its motion from a shaft *Y*, placed at right angles to and communicating by means of

¹ In reference to these nozzles and side pipes, Fenton and Murray brought an action against Boulton and Watt for an infringement on their patent for working one valve through the other; but it was decided that Mr. Boulton's Mint Engine had been working with valves similarly constructed for a length of time previous to their patent.

bevelled wheels with the crank-shaft. Four arms, 9, 10, 11, and 12, are fixed to the rods *vv* and *ww*, for the purpose of moving the valves, and a lever or handle (13), turning on a pin screwed on the pipe E, is used to open and shut the steam-valves when the engine is first set to work (see art. 511); the steam-gauge, 21, is for measuring the pressure of the steam above that of the atmosphere (art. 503), and the condenser-gauge, 24, is for measuring the force of the vapour in the condenser (art. 504).

Figs. 3, 4, 5, and 6 represent the four-way cock as executed by Maudslay. Fig. 5 is the plan taken at the horizontal line D E, in figs. 3 and 4, which are sections through the steam-cock. In these figures, E is the steam-pipe, and F the pipe leading to the condenser. Fig. 4 is the steam-cock or cone ground into its seat, and provided with a grease-cup, to afford a regular supply.

Fig. 6 is a plan of the upper side of the steam cone. (See art. 402.)

PLATE IX.

The apparatus for opening and closing the steam passages is of more importance to the perfection of the steam engine than any other part of its mechanism. In the present state of the engine, the action is either very complicated or imperfect. My object in this Plate is to show how the imperfection of the most simple method may be avoided, and also how it may be applied to reciprocating movements.

Fig. 1 shows a section,¹ and Fig. 2 a plan, of an apparatus for opening and closing the steam passages by means of the rotary motion of the crank-shaft D: the object of the method is to give such a form to a wheel on the shaft D as will move the pin *e* twice during the stroke, and in the easiest and quickest manner. For this purpose, the shaft passes through a rectangular frame which rests in grooves on the shaft to keep it in its place, with liberty to slide backwards and forwards; and it is provided with two rollers, to be acted on by the curved surfaces of a wheel fixed on the shaft. The curve H G moves the valves at the termination of the stroke, and I K shuts off the steam, that the engine may work expansively the rest of the stroke. In order that there may be the power of varying the time of cutting off the stroke, the curve I K may be on a separate piece M, (fig. 2,) capable of being moved from N to O. The apparatus is supposed to move a slide of the kind represented in Plate V. fig. 1, but is equally applicable to move the four-passaged cock (arts. 401 and 403) or valves. For the nature of the curves, see art. 426.

Figs. 4 and 5 represent the same principle applied to a reciprocating motion. The plug-tree A B is kept in its place by guides on the brackets; these guides slide in the dark grooves. The curved parts H I, C D, K L, &c., successively move horizontally the frame C on four rollers supported by the brackets attached to the engine; and by the backward and forward motion it turns the axis E, and raises or depresses the lever F, which acts on the rod of the slide. The same movement would obviously open valves or turn a cock. By the lever on the right-hand side, the roller frame may be moved by hand; but by not reversing fig. 5, it has been shown there on the left. (See art. 428.)

Fig. 3 represents the method of opening valves by weights, the plug-tree A B being made a means of raising the weights, and of disengaging them by the tappets *f d*. (See art. 423.)

PLATES X. AND XI.

The figures of these Plates are to illustrate the combinations used to produce rectilinear motion from motion in a circular arc.

Fig. 1 is the parallel motion used for steam-boat engines. The beam A F is below the cylinder; from

¹ Fig. 1, as represented in the Plate, is too much limited to allow the motion to be reversed.

G, the end of the cross-head, draw a line to A, the centre of the axis of the beam, and it will cut the rod D B in E, and the length of the radius bar C D may be found by art. 437: when E B is equal to E D, the length of the bar C D is equal to A B; and this is the best though not always the most convenient form. The rod D' G may be at any height, provided it be parallel to A F; and B may be at any point in A F, if the position of C is not limited.

Fig. 2 shows the most common construction for engines with the beam above the cylinder. H is the piston-rod connected at G, and C D is the radius bar. The line G A cuts the link B D in E, the proper point for the air-pump rod.

Fig. 3 shows a plan of the upper side of the beam, where C D, C D are the radius bars; and the beam is in two parts, as is usual in large engines.

Fig. 4 is a diagram to illustrate the investigation of the properties of the combination in its most simple form. (See art. 434.)

Fig. 5 is a diagram for the apparently more complicated case, when the rod is fixed to one angle of a parallelogram. (See art. 437.)

Fig. 6 shows how to arrange for three piston-rods to move parallel, as for Woolf's engine: the points of suspension must be all in the line A G; and any number of them may be similarly adapted.

Fig. 7 shows another arrangement for three rods at one end, and two at the other end of the beam. (See art. 440.) The dotted arcs show how the centre C for the radius bar may be determined geometrically, by drawing a circle through the three positions D d d' of the point of connexion.

In all the cases the corresponding points are marked by the same letters, and therefore by referring to the investigation of fig. 4, the relations may be traced: the particular forms of different engine-makers will be found by turning the part upside down, altering the place of the parallel bar G D, or altering the proportions of the parts. In every combination where the bar C D is not equal to A B, the variation from rectilinear motion increases with the extent of the angle described.

Variations of the parallel motion are exhibited in some of the other Plates.

Fig. 8 is designed to show that the vibrating pillar motion is exactly the same in principle, and only differs in the particular mode of combination. (See art. 439.) Fig. 9 is a particular case.

Figs. 10 and 11, parallel motions for steam-boat engines, show how the point of connexion of the radius rod may be determined by geometrical construction. Thus, having determined the three points H h h', set off h k equal to C h'; join C k, and bisect it with the straight line n d, meeting k h d in the point required: for since k d = C d, and h k = C h', we have h d = h' d'; and hence when d arrives at d', h will coincide with h', and the motion will thus be properly adjusted. Fig. 1 may be constructed in this manner. (See art. 437.)

Fig. 12 exhibits a simple parallel motion, and is easily constructed geometrically by finding C, the centre of a circle, passing through the three points D D' D''. Fig. 13 shows how a pump-rod may be attached to this motion.

PLATE XII.

This Plate represents a plan and elevation of an atmospheric engine for raising water from a mine. The beam is supported by a frame of cast iron, designed so that it may be taken apart when it is necessary to move the engine to another mine (art. 523). The steam comes from the boiler by the steam-pipe S, and is admitted to the cylinder C by a sliding piston in B (see fig. 2, Plate VI.); and then the piston in the cylinder C rises to the top of the stroke, and the piston-rod forces the end f of the beam up with it: as the beam rises, it draws the rod F G with it, which, near the

end of the stroke, moves the sliding frame H (art. 428), and by the rod O the slide in B, so as to shut the steam off, and open the passage to the air-pump A: into the passage a jet of water plays at I. The piston then begins to descend by the pressure of the atmosphere and raises the pump-rods, and at the end of the stroke the part F of the rod FG moves the slide, and shuts the passage to the air-pump, and opens that for the steam. (See Plate VI. fig. 1.)

The parallel motions¹ are guided by radius rods attached to the frame (arts. 436 and 440).² The sliding frame H is supported by a cross bar beneath H, and another at K, and the slide may be moved by hand by the lever M. Cold water for injection is supplied by the pump E, and water is raised from the hot well by the pump D, and passes to the boiler by the pipe Q, with a small branch pipe at P, to give water to the top of the piston. (See arts. 345–350.)

PLATE XIII.

This Plate shows an elevation of a single-acting engine, as executed by Messrs. Boulton and Watt. The boiler *a* is enclosed in a case of brickwork, and the steam passes by the steam-pipe *b* to the cylinder *c*, which is firmly attached to the floor of the engine-room by the bolts *d d*: its upper end is covered by the lid *e*, through which the piston-rod *k* slides in an air-tight box called a stuffing-box. The beam *fg* moves on its axis or gudgeon at *h*; and the bearings in which the gudgeons work are sustained by the floor and wall *i*.

The pump-rod *j*, carrying a counter-weight, is suspended at the end *g* of the beam; and both it and the piston-rod *k* are connected by a parallel motion apparatus to the working beam *fg*. (See art. 437.)

The condensing cistern is at *m*, and contains the air-pump *n*, the condenser, and hot well *o*: a continued supply of cold water is procured by the action of the cold-water pump *p*, and the excess is carried off by a waste-pipe to the well *q*; the whole of the external part of the apparatus being kept by that means at the lowest temperature possible.

The upper steam-valve is at *r*, and the lower at *s*, and the exhaustion valve at *t*. (See fig. 5, Plate V.) These valves are moved by the plug-tree *v*, which is furnished with tappets to give motion to the levers acting on the valves *r s t*. (See art. 423.)

The pump to raise water from the hot well *o*, to supply the boiler, is at *u*, and the water is conveyed by the pipe *ww* to the small cistern *x* on the top of the feed-pipe, which is provided with a valve, and acted on by a lever connected by a wire passing down through a stuffing-box *y*, to a stone float in the boiler, which by its descent opens the valve, and allows the admission of an additional supply of water when it is required (art. 196).

In order to prevent concussion, two blocks 1, 2, are fixed across the upper side of the beam, and

¹ In the parallel motion apparatus, shown in fig. 1, the vibration of the beam is not bisected. (See p. 251, note to art. 437.)

² In this Plate, as published in the former editions and as originally drawn by Mr. Tredgold, there was one parallel motion at the cylinder end of the beam only. In order to remedy an obvious error of construction in that arrangement, (first noticed by Professor Willis, of Cambridge,) I have, without departing from the principle of Mr. Tredgold's frame-work, added another parallel motion with a separate radius rod to the other end of the beam.—*Ed.*

extend on each side so as to strike on four wooden springs, on the floor which supports the beam. (See art. 494.)

For large engines the beam is in two parts, with a space between them, as shown in fig. 3, Plate X.

The proportions of the single engines are given in Sect. V. arts. 351–358; the application, in arts. 517, 518, 527, and 532; their effects, art. 521; and their power and consumption of fuel, Table II. p. 341.

PLATE XIV.

This Plate represents a double-acting steam engine for raising water (arts. 515, 527).

The steam from the boiler enters by the steam-pipe S, passes through the top valve *a*, to act on the piston *p*, and forces it down; and just before it arrives at the bottom of the cylinder, the plug on the rod R will come in contact with a lever, and shut the valves *a b*, and open *c d*, which were shut; the steam will now continue its course down the pipe S through the valve *d*, act on the bottom of the piston *p*, and again force it up to the top of the cylinder, while the steam which forced it down will make its escape to the condenser B, through the valve *b*, by a pipe which conveys the steam from the valves to the condenser.

Having described one double stroke of the engine, it is only necessary to remark that its continued motion is made of a repetition of the same thing over again. The steam which passes to the condenser B meets with a jet of cold water from the injection cock I, and the greater part of it is reduced to the state of water, and it is the office of the air-pump A to clear it away. The rod R works the air-pump which draws out all the injected water, air, and condensed steam, and discharges it through the valve at the top of the air-pump into the hot well, where a certain portion of the water is again forced back to the boiler by the force-pump L, and the remainder runs to waste: at the same time, to the other end of the great beam is attached the rod of the cold-water pump N, which supplies the cistern containing the condenser and air-pump with cold water; and from this source the injection cock has its supply.

The governor Q is put in motion by bevelled wheels on the shaft of the fly-wheel P (art. 485), and regulates the throttle-valve in the steam-pipe S, so as to close it a little for a less admission of steam when the speed is increasing; and on the contrary, when the engine relaxes in its speed, the balls will again begin to fall, and open it a little, so as to admit more steam: by this means the work may vary, and yet a uniform motion be kept up by the engine (art. 495).

In the pumping apparatus, the rod M is the pump-rod for the purpose of raising water; when the rod descends, the water will be forced through G into the upper air-vessel E, from whence it passes in a continued stream to the reservoir, at a distance and height proportional to the power of the engine. The barrel of the pump will be refilled from F, the source which communicates with the lower air-vessel H; when the rod rises, the opposite valve at the top will open, and the water will be forced through into the air-vessel E, and the supply for the descending stroke will rush in by the bottom valve from F, and, as before, be discharged through G.

For the proportions of this kind of engine, see arts. 359–368. I would recommend the adoption of Field's valve instead of the throttle-valve. (See art. 492.)

PLATE XV.

This Plate represents a double-acting steam engine, for impelling machinery, as executed by Messrs. Fenton, Murray, & Co., of Leeds.

The engine is supported by the walls A A A A, part of which form the walls of the engine-house. The steam cylinder B is secured to the wall below it by bolts; it is enclosed in a jacket or casing of cast iron, a little larger than the cylinder, and the space between them is supplied with steam, to keep the temperature of the cylinder as near to the temperature of the steam as possible. (See art. 100.) The steam comes from the boiler by the steam-pipe C C to the valve-pipe D D, and passes to the condenser by the eduction pipe E E, leading to the condenser F, which with the air-pump G is immersed in the cold-water cistern H, supplied through the pipe J. The cold-water pump I is worked by the rod O attached to the engine-beam. The air-pump is worked by the rod N, and delivers the water into the hot well, from whence the hot-water pump K, worked by the rod P, the upper part of which is connected with the working beam at Q, raises a quantity of hot water to supply the boiler.

The working beam Q is supported by the cast-iron column R, and is connected to the piston-rod L by the parallel motion M M (see art. 133); the other end of the beam gives a rotary motion to the crank-shaft by means of the connecting rod S, the lower part of which is attached to the crank T; and the spur-wheel U on the crank-shaft, working into a pinion on the shaft V, gives motion to it, and to the fly-wheel W (see art. 485). By means of a train of shafts and bevelled wheels X Y Z, moved by the crank-shaft, the axis, carrying the eccentric rollers which move the valves, is kept in motion, and the rods *a b*, which are connected to the valves, are raised and depressed at the proper times, or by hand by the lever *e*, in the manner more fully described in Plate VIII. In some of their engines they use slides nearly of the kind mentioned in art. 392. The injection of cold water to the condenser is regulated by a cock, moved by the handle *c* on the spindle *d*.

The governor *g* (see art. 495) is kept in motion by bands from the crank-shaft, and opens or closes the throttle-valve in the steam-pipe C by means of a lever *h h*. (See Plate VIII. fig. 1.)

The proportions of the parts for a double engine of this kind may be ascertained by arts. 359–368. It ought to be made to work expansively, but in this case it has not been done: the saving resulting from causing the engine to work expansively will be in the ratio of about 10 to 7 to do the same work (art. 367. See Table III. p. 342.)

PLATE XVI.

As an example of a portable condensing engine for impelling machinery, I have taken that of Mr. Maudslay, where the beam is omitted, and the crank connected directly with the piston-rod. Fig. 1 is a front elevation of an engine; Fig. 2, a longitudinal section; and Fig. 3, an end view. The cylinder B is supported by a cast-iron frame A, and C is the piston, with the rod D, connected to a cross-head at E, and guided by the wheel F, which keeps the piston-rod in a vertical direction, by moving the frame G; the side rods H H connect the cross-head E with the double crank I I, which turns in the plummer-blocks or bearings J J, one on each side of the frame, and to which the fly-wheel shaft K, carrying a fly-wheel M, is connected by a coupling box, or clutch L, at the end next the engine.

Two eccentric wheels *NN*, on the crank-shaft *K*, give motion to the levers *O* and *T*, by means of the connecting rods *PP*. The lever *O*, supported by the bearing *Q*, works the cold-water pump *S*, by the rod *R*; while the beam *T*, working on the centre *V*, works the air-pump *X* by the slings *v*, and the hot-water pump *Y*; which by the feed-pipe *Z* supplies the boiler with hot water. On the cross rail (*a*) the guide is fixed to confine the air-pump rod to a vertical motion; the condenser *b* surrounds the air-pump, and is again surrounded by one of the cold-water cisterns *c*; the two cisterns are connected by a pipe *d*: the steam from the cylinder passes to the condenser through the eduction pipe *e*, and the cold water for injection is admitted to the condenser by the cock *f*. The air and condensed steam ascend through the foot-valve *g* in the bottom into the air-pump. The mechanism for opening and closing the steam passages consists of an eccentric piece *k*, fixed on the crank-shaft, the action of which communicates a reciprocating motion to the rod *i*, which by a bent lever moves the connecting rod *l*, and lever *m*, that is fixed at one extremity of a spindle having a bevelled wheel at the other; which works into another on the spindle *n* of the steam-cock *o*, by which the steam is admitted from the steam-pipe to the cylinder. The engine is worked by hand by means of the handle *h*.

A pair of bevelled wheels on the fly-wheel shaft gives motion to the governor balls, and these raise or depress the piece marked *p* on the axis, which by its peculiar form acts on a lever, and retains the valve in the steam-pipe at *q* open for a longer or shorter time for the admission of steam according to the velocity of the engine. (See art. 492.) There is also an apparatus for working the throttle-valve by the same governor.

This engine is in a very compact form: it is however a little too complex, and its frame reminds one of an antiquated style of cabinet-work; but the beauty of the workmanship is unequalled, and is faithfully represented by Mr. Clement's drawings.

To proportion the parts of an engine of this kind, see arts. 354–367, and the articles there referred to; and Table III. (p. 342.) It is adapted for engines of from 2 to 30 horse-power.

PLATE XVII.

Figs. 1 and 2 represent the instrument called the indicator, for measuring the force of the steam in the cylinder of an engine. (See art. 505, and p. 289, note.)

Figs. 3 and 4 are diagrams to illustrate the comparative stability of opposite classes of forms for vessels. (See arts. 544, 545.)

Fig. 5. If the motion of a vessel be always direct, its sides should be parallel, and one of the section fig. 3 may be terminated by making both the extremities of the same figure, and formed by circular arcs; then if the section be similar, so that the stability may be equal throughout the length (art. 544), the water lines will increase in curvature towards the keel (they are shown by dotted lines); but the actual obliquity of the resisting surface, by which these resistances are measured, decreases in descending. The objection I should make to this mode of forming a vessel is, that it would not have a sufficient tendency to keep in its course; and I think a better form would be obtained by conceiving the midship section to advance parallel to itself, and also towards the keel, in the same manner as is shown in the next figure.

Fig. 6. If the section fig. 4 be the midship section, and the plan of the load-water line be formed by arcs of circles, and the sections be all drawn by the same mould as the midship section, as far as the breadth at the part allows, then the form will be as fig. 6; the water lines would be all of the same curvature, the capacity would be easily measured, and the construction would be simple.

But it is necessary to remark, that parallel sides are best only for direct motion. In an oblique motion, such as that almost universally produced by wind, the vessel should diminish towards the stern; the oblique force of the wind then presses its side against the fluid so as to produce an effect similar to that of an inclined plane, if the sails be properly set, and I think the diminution should commence where the curvature of the fore-part ends.

It is chiefly for direct motion that a steam vessel is intended, and where it is so, parallel sides have the advantage; but where sails are to be used with effect in addition to steam-power, the direct resistance must be a little increased, or the capacity diminished, to get a clear run when the oblique force of the wind is available. Hence it appears that a vessel adapted for one mode of action is not the best for another; and instead of theory being imperfect, it is evident that it only wants to be followed up by analysing the different cases which occur in practice. It is difficult to conceive how much this subject has been neglected, or how much remains to be done.

PLATE XVIII.

Fig. 1 is a section of a steam vessel with its boiler in two parts; the right part is shown in a section across it through one fire-place F, and its flues N P; and through the cross flue L of the other fire-place, and through the safety-valve U (art. 208); showing the dampers O R, and the passage of the flues to the chimney. Of the left part the fire-door end is shown with the fire-doors D D, the handles for clearing the clinkers B B, the doors for cleaning the flues at E E E, and the gauge-cocks G; also part of the chimney C, the steam-pipe S, and a slide-valve V, to shut off the steam from the engine. There should be as much space between the boiler and the sides of the vessel as to admit a person to go round to examine it. The floor under the boiler should be rendered as strong as possible, and the boiler should rest on a plate of iron bedded on a layer of bricks or tiles laid over the floor in cement; in this manner a thin plate of wrought iron extending under the whole, being flexible, and brick a slow conductor of heat, is more secure than a much thicker cast-iron plate.

Fig. 2 is a plan showing the arrangement of the two fire-places F F, and their flues. The fire-door is at D, the fire on the grate F, the clinkers fall at H, and the smoke turns at L and returns along the flue N, rises at O, and goes back along a flue P over N. The boilers should be strengthened by internal frames disposed in triangles, and so as to afford supports for the flues.

Fig. 3 is a longitudinal section through the boiler, and one of the fire-places:¹ the same letters refer to the same parts in all the figures; see arts. 184-189: for the fire and flue surface, art. 149; for the capacity, art. 160-165; for the area of the chimney, art. 223; for safety-valves, art. 204-217; for the strength of boilers, art. 470; and for the management of sea water, art. 510.

PLATE XIX.

To Boulton and Watt steam navigation is indebted for the effective method of working two engines jointly, giving, with other advantages, a more equable motion to the paddle-wheel, and, in the event of accident to one of them, enabling the vessel to proceed with the other at about two-thirds of her greatest velocity.

¹ In this last figure there is scarcely sufficient space allowed for the action of the slide-valve V.

This Plate is an isometrical projection¹ of a steam-boat engine, in the manner they were first arranged by Messrs. Boulton and Watt; and nearly the same general principle of construction is followed by all the best manufacturers. Two small engines connected in this way were adapted to the 'Prince of Orange' and 'Princess Charlotte,' on the Clyde, by these gentlemen, in 1814. Previous to this, it had been the practice to employ only one engine, ranged by the side of the boiler, having a fly-wheel on the paddle axis to assist the engine in passing its centres; and in such case the occurrence of any accident immediately put an end to the progress of the vessel by steam.

The steam comes from the boiler by the pipe in the front of the figure, and passes into the steam-case and round the cylinder to the slide-box, from whence it is let into the cylinder in a manner which will be more clearly understood by referring to the next Plate: from the lower part of the cylinder a trunk proceeds to the condenser, which is below a square cistern; beyond which a part of the air-pump is seen, and to the left of it the hot-water pump to supply the boiler.

The motion of the parts commences at the cylinder: the piston-rod is supposed to be descending, and by means of a cross bar (called a cross-head) and two side-rods, it depresses the ends of the side-beams, these side-beams moving on axes in the centre; the other ends rise and force a cross bar upwards, to the middle of which the connecting rod is fixed, by which the crank of the paddle-wheel shaft at the upper part of the figure is turned; and also by the rising of the further end of the side-beams, the cross-head of the air-pump and hot-water pump is raised by two side-rods. The motion of the piston-rod is guided by a combination of rods called the parallel motion (see art. 440), and the slide is moved by an eccentric wheel on the crank-shaft; and to reduce the friction its weight would cause, it is balanced by a heavy ball acting on a lever below it.

Though the figures on the next Plate are not a plan and section of this engine, yet the same parts, with the exception of the steam-pipe, are nearly in the same places; and hence, by comparison of the two, the uses and action of the parts may be understood.

The weight of an engine of this kind is not exactly proportional to its power, but is nearly so; and that of a forty-horse-power engine, with proper duplicate parts, water, and other appendages, is about 100 tons. See Section IX.

PLATE XX.

In this Plate, Fig. 1 is a section, and Fig. 2 a plan, of a steam-boat engine. A strong frame of cast iron supports the crank-shaft I, and connects the parts of the engine; and the whole is sustained by two strong beams on the floor. The steam-pipe S brings the steam from the boiler to the passages of the slide, and from thence to the top or bottom of the cylinder A, and it passes from the slide to the condenser B, where it is condensed by a rose jet playing constantly; the air-pump C expels the air and water into the cistern D, from whence it runs out by a pipe. The motion of the piston is transmitted to the crank by means of the double side-beams or levers E F, moving on the axis G; these are connected to the cross-head of the piston L L by two rods called the side-rods, and the ends E are connected to the crank by the connecting rod H. The air-pump is also worked by side-rods from the side-beams, and the hot-water pump from the same cross-head.

¹ Some account of this simple and useful mode of drawing, which was invented by Professor Farish, is given in Dr. Gregory's 'Mathematics for Practical Men,' new edition, edited by Henry Law, C.E. 8vo. 1849.

The parallel motion is guided by the radius rod M N (see art. 434): the vibration of the beam is not bisected (see page 251, note). The slide is on Murdoch's construction (art. 392), and is moved by a wheel on the crank-shaft I, with a sliding frame P (art. 426), and by hand by the lever T; the slide-rod being moved by slings from the arm R. The valve O is used to let steam into the condenser in setting the engine to work, and the air and water are blown out at the discharge valve into the cistern D.

For the strength of the parts, see art. 441; the proportions of the engine, arts. 354-367. The parts of the slide should be counterbalanced, in order that its resistance may be equal in either direction.

Each vessel generally has two of these engines, placed parallel to one another, with a passage between them; and there is room left for working the fires between the cylinder and the boilers. The coals should be kept in iron tanks in the engine-room, each to hold a given weight of coal, with the object of ascertaining with accuracy the consumption for any time; about four tons is a sufficient quantity to be together, and they should be kept out of the danger of taking fire.

The proportion of the power to the effect is given in Section IX., art. 600.

PLATE XXI.

This Plate, which represents Kingston's valves, is given by Mr. Dinnen as connected with the subject of his valuable Paper on Steam Boilers; and the following is his description, &c.

I.—BLOW-OFF VALVES.

- a*, Gun-metal pipe with conical base, passing through the ship's bottom, with the conical part outwards and made even with the same. Inboard, the cover of the pipe (forming the gland or stuffing-box and the nozzle which joins to the stop-cock of the blow-off pipe) is screwed on the upper end of the pipe, down to the ship's floor, on to a chock of wood fitted thereon as requisite, in the manner of a screwed bolt and nut.
- b*, The valve, fitted within the cone of the pipe and opening outwards, having a copper rod which passes through a stuffing-box in the cover. A guard protects the valve beneath.
- c*, Cover, which is screwed tightly on the pipe.
- d*, Gland or stuffing-box.
- e*, Handle for lifting the valve.
- f*, Nozzle, with a flanch for connecting the valve with the stop-cock of the blow-off pipe.
- g*, Guard, extending across the base of the pipe, and having no guide-spindle passing through it; for the object of allowing the valve to be pressed entirely on one side, thereby affording a more ready passage to any matters intruding into the pipe from the boilers.
- x*, Planking of the ship's bottom.
- m*, Timbers of the ship's floor.
- n*, Chock, fitted on the timbers to accommodate the required length of the pipe.

II.—INJECTION VALVES.

- a'*, Gun-metal pipe, passing through the ship's bottom.
- b'*, The valve, having a guide-spindle below.

- c'*, Cover, screwed on the pipe.
d', Gland, or stuffing-box.
e', Handle of the valve.
f', Nozzle with flanch for connecting the valve with the stop-cock of the injection pipe.
g', Guard, so constructed as to form a grating, in order to prevent weeds or other substances from being admitted into the condensers; and having a socket rising from the centre, through which the lower spindle of the valve passes.
h'h', Two copper standards, screwed into the cover, having mortises or key-ways through them, which coincide in direction with a corresponding one in the rod; and are so adjusted, that when the valve is completely open, a key passing through them maintains the valve in its place, and thereby prevents its being closed by the pressure of the water without rushing in to fill up the void in the condensers.
i', Key, or cutter, for fixing the valve as above.
m', Ship's timbers.
x', Planking of the ship's bottom.

III.—HAND-PUMP VALVES.

These are the same as the injection, with the exception of the grating.

MANNER OF FIXING THE VALVES IN THEIR PLACES.

The situation of the pipes being fixed, a close jacket of fearnought, well covered on both sides with a mixture of white and red lead, is sewn on from the base to the lower part of the screw, and a corresponding hole is formed in the ship's bottom.

Then the pipe, being *set* up in its place by shores, is firmly screwed up by the cover, and the space between the cone and a corresponding flanch of copper sheathing (extending two or three inches up between the planking and the cone, to protect the former from the attacks of the worm) is well caulked; this done, a copper screw is fitted through the lower part of the cone, into the wood, to prevent the possibility of the pipe turning or heaving the cover on or off.

The cover is now taken off, and the space around the upper part of the pipe is caulked; then it is finally replaced and screwed down on a copper washer of about $\frac{1}{8}$ inch in thickness.

The chocks are well coated on their under sides with red and white lead.

PLATE XXII.

BOILERS OF H. M. STEAM VESSEL 'AFRICAN.'

See the description of the next Plate.

PLATE XXIII.

BOILERS OF H. M. STEAM FRIGATE 'MEDEA.'

This and the preceding Plate are also furnished by Mr. Dinnen in connection with his Paper on Steam Boilers. The following is his description:

(The same letters refer to corresponding parts in the several views.)

- a*, Furnaces.
- a'*, Grate-bars.
- a''*, Bearer-bars.
- b*, Ash-pits.
- c*, Bridges.
- d*, Flues.
- e*, Smoke-joints, } for connecting the fore with the after boilers.
- e'*, Steam-joints, }
- f*, Uptake, through which the smoke, &c. passes from the flues to the chimney.
- g*, Chimney.
- h*, Air casing, which surrounds the base of the chimney to prevent too great a transmission of heat to the deck, or other materials liable to be injured thereby.
- i*, Dampers with their levers, for checking the draught of the furnaces.
- j*, Water-ways between the flues and fire-places.
- j'*, Water-ways of the bridges, and beneath the flues and fire-places, such that one may enter at the mud-hole doors, forward and aft, and pass over the entire bottoms of the boilers, and under the flues.
- k*, Mud-hole doors, with a similar one on each after-boiler.
- l*, Furnace-doors.
- m*, Clinker-bars, for supporting the levers employed in clearing the furnace-bars.
- n*, Feed-pipe, with two branches and valve-boxes, for supplying the boilers with water.
- o*, Floats, with indexes, for showing the height of the water in the boilers.
- p*, Glass water-gauges, through which the exact height of the water is seen.
- q*, Gauge-cocks, below which the water is never supposed to descend.
- r*, Steam-chests.
- s*, Safety-valve box, containing the two safety-valves, with the waste steam-pipe rising from the same.
- s'*, Waste steam-pipe.
- t*, Pipes for conveying the water overboard from the safety-valve box, and likewise that resulting from the condensation of the steam in the 'globe, or other contrivance at the head of the waste steam-pipe.
- u*, Safety-valve levers; accessible at the front of the boilers, the safety-valves being lifted by other levers fitted to the same axes, within the steam-chest.
- v*, Man-holes, with their covers in place.
- w*, Communication valves, having screwed spindles, which are acted on from above by two levers, for the purpose of shutting off either boiler from the main steam-pipe.
- x*, Main steam-pipe.
- y*, Reverse valves, to prevent the boilers collapsing by the pressure of the atmosphere, which, in case of a vacuum being formed, presses the valves inwards to restore the equilibrium.
- z*, Vacuum pumps, the rods of which are attached to levers on deck, by working which, on charging the boilers with water from the sea, an exhaustion is effected which causes the water to rise within, from the pressure of the atmosphere without, and thus saves the labour of forcing many tons of water into them. The time occupied in fully charging the boilers of the 'Medea' by these pumps was usually from fifteen to twenty minutes.
- z'*, Blow-off pipes, with a nozzle to each boiler.

The same description applies generally to Plate XXII. of the African's boilers, which are fitted with precisely similar appendages, with the exception of the vacuum pumps.

PLATE XXIV. (Marked, in error, as Plate 28.)

MORGAN'S PADDLE-WHEEL AND SEAWARD'S PADDLE-WHEEL.

This Plate relates to Mr. Rennie's Paper on Paddle-wheels, in which they are fully described.

PLATE XXV. (Marked, in error, as Plate 29.)

POSITIONS OF A FLOAT OF A RADIATING PADDLE-WHEEL, AND ALSO OF A VERTICALLY-ACTING WHEEL IN A VESSEL IN MOTION.

For a description of this Plate, see Mr. Rennie's Paper, already referred to.

PLATE XXVI. (Marked, in error, as Plate 30.)

CYCLOIDAL PADDLE-WHEEL FITTED TO THE 'GREAT WESTERN' STEAM VESSEL, WITH ANOTHER DRAWING REPRESENTING THE POSITIONS OF ONE OF THE FLOATS.

This Plate also relates to Mr. Rennie's valuable Paper, where it is described by him.

PLATE XXVII. (Marked, in error, as Plate 31.)

This Plate is designed to illustrate Captain Oliver's Paper, to represent a scale of different courses from the Cape of Good Hope to the Isle of France, with the several distances marked.

PLATE XXVIII. (Marked, in error, as Plate 33.)

This Plate exhibits the various situations of a trial at sailing of her Majesty's steam ship of war 'Medea,' with the 'Caledonia,' 'Vanguard,' and 'Asia.' For particulars, see the end of Captain Baldock's excellent Memoir on the 'Medea.'

PLATE XXIX. (Marked on Plate as 1.)

In 1816 a vessel ('Caledonia') was purchased by Messrs. Boulton and Watt, and fitted with two engines of fourteen horses' power, solely for the purpose of making experiments under various circumstances and modifications of paddle-wheels. One of these experiments embraced the ascension of the Rhine in the winter of 1817, as high as Coblenz.

The Plate represents a side view and plan of the engines manufactured by Boulton and Watt for the 'Red Rover' and 'City of Canterbury' steam vessels. This form of marine engine, adopted by them in the year 1817, was fitted on board the 'Favourite' in April, 1818, and some slight improvements were subsequently made by themselves.

In the first edition of this work it was mentioned in mistake, that they had adopted it from the 'Clyde.' This is incorrect: it should be distinctly stated that the mode of construction is due to Boulton and Watt, and that a preference has been given to the arrangement by several of the best makers who have followed it.

PLATE XXX. (Marked on Plate as 2.)

This Plate is a longitudinal section of the preceding engine with boiler attached, and the same reference letters apply to both.

The engines and boiler stand on sleepers of oak X X; African oak, from its stiffness, being generally employed. The base of the engine is secured by bolts passing through the sleepers and bottom timbers.¹ The steam-pipe S brings the steam from the boiler to the space between the slides *c*, and by their movement admits it to the top and bottom of cylinder A. At the termination of each stroke it passes to the condenser B, by the upper and lower eduction pipes C and D, and is there condensed by a jet of cold water. The air-pump E withdraws the air and water from the condenser to the hot-water cistern F, which, being close at the top, forms an air-vessel to expel the water from the cistern through the waste water stop-valve pipe G.

The motion of the piston-rod is transmitted to the crank by means of the main levers H I, moving on the main gudgeon K. These are connected at the cylinder and to the cross-bar of the piston by two side-rods L L, and the other end, I I, to the crank by the connecting rod M.

The air-pump E is also worked by two side-rods from the main levers, and the hot water and bilge-pumps from the same air-pump cross-bar N.

The piston-rod is guided by a parallel motion *a a*, the slides *b b* are separate, but connected by a rod similar to their land construction of 1808. These and the upper eduction pipe were afterwards applied by Boulton and Watt, and may be considered a great improvement upon the long slide, where the expansion of the metal is liable to twist the face and render them leaky.

Motion is given to the slide-valves by the eccentric circle O, by means of the eccentric rod *d*, connected with the eccentric arm *e*, from which it may be disengaged with facility when the engines are required to be stopped; *f*, the working gear shaft, receiving its action from the eccentric arm.

P P, upper and lower blow-valves; the former is used, before starting the engines, to admit steam into the condenser to blow out the air and water by the lower valve, so as to form a partial vacuum in the condenser.

Q and R, upper and lower headstock frames which support the engine and paddle-shaft connected with the hot-water cistern and cylinder casing, the ribs or webs of which are disposed in the direction of the strain: there are many more fanciful and pleasing forms, but certainly none so mechanical or so well adapted to the purpose. T, injection pipe through side of vessel; *g*, bilge injection; to be used in the event of the vessel leaking to any extent, in which case the river injection would be shut off, and the bilge one opened. This is an appendage which has till lately been overlooked by other makers, but a very necessary one, as by such means about four gallons per horse-power per minute might be withdrawn by injecting from the vessel.

U is a longitudinal section of the boiler; V, the grate; and W, the flues; *y*, safety-valves enclosed in

¹ It may not be irrelevant to notice here, that owing to this mode of securing the engines, the proprietors of the 'Red Rover' were subsequently enabled to raise that vessel when sunk in forty feet of water.

the safety-pipe, and perfectly inaccessible to the engine-man for the purpose of applying extra weight to endanger the boiler. This description of valve was used by Boulton and Watt in 1814, in a vessel fitted on the Tyne, consequently three years previous to the examination before a Committee of the House of Commons for some such precaution. *h h*, blow-out pipes and cocks; *iii*, feed-pipes; *k k*, &c., hold-down bolts, occasionally cased with brass to prevent corrosion.

PLATE XXXI. (Marked on Plate as 3.)

This Plate represents, with similar reference letters, a transverse section of the same splendid steamers, the 'Red Rover' and 'City of Canterbury,' showing on the left the cylinder, and on the right the crank end of the engine, with the paddle-wheels, main beams for support of paddles, stays, &c., &c.

PLATES XXXII. XXXIII. and XXXIV. (Marked on Plates, in error, 5, 6, 7.)

ENGINES OF HER MAJESTY'S STEAM FRIGATE 'PHŒNIX.'

These three Plates represent a plan, side elevation, and transverse section of the steam engine of Her Majesty's steam frigate 'Phœnix;' they also describe the engines of the 'Medea,' 'Rhadamanthus,' and 'Salamander,' the machinery of these four vessels being identical, and all manufactured by Messrs. Maudslay, Sons, and Field.

The general arrangement of these engines is on the ordinary side-beam construction; all the working part, except the beam, of wrought iron; metallic piston; and the crank-pins are so arranged that the wheels may be readily disconnected for sailing.

The boilers are of iron, in two independent parts, and furnished with valves so contrived that they may be used either separately or both together.

The wheels are of the ordinary construction, except those of the 'Medea,' which are Morgan's; some of the others have had cycloidal boards applied to the original wheels.

The proportions of these engines are as follows:

The nominal power is	.	.	110 each, or 220 H. P. collectively.
Diameter of cylinder	.	.	55½ inches.
Length of stroke	.	.	5 feet.
Diameter of wheels	.	.	21 feet. 8 feet 6 inches wide.
The 'Medea,' Morgan's	.	.	24 feet. 5 feet 8 inches „
Length of engine-room	.	.	58 feet.

The tonnage of the 'Phœnix,' 'Rhadamanthus,' and 'Salamander,' is about 800 tons; that of the 'Medea' being 807 tons. They carry two heavy traversing guns, 10 calibre, which throw an 84-pound shot; one of these guns is placed in the bow and one at the stern; below they carry four 18-pounder carronades, with provisions for 120 men. They can stow from 200 to 300 tons of coal at a draught of water of 14 feet.

The consumption of coal being 15 tons per day, they can steam from 15 to 20 days.

The scale of the drawings is ¼ of an inch to the foot.

PLATE XXXV. (Marked on Plate, in error, 8.)

ENGINES OF THE GRAVESEND PACKET 'RUBY.'

This celebrated vessel, undoubtedly a very fast and long-tried Gravesend packet, was built by Mr. Wallis, of Blackwall, near London, in the year 1836, from the designs and specifications of Mr. O. W. Lang, Jun., late of Her Majesty's Dockyard, Woolwich. The engines were made by Messrs. Seaward and Co., of the Canal Iron Works, near London.

The very great success of this vessel, which beat many competitors from the time of her starting, may be attributed to two principal causes:

First, to a most judicious arrangement in the form and construction of the vessel, by which the quantity of materials used in the building are brought so to bear upon one another that each piece performs the office assigned to it; and no more timber is used than what is requisite to give the ship the necessary strength and solidity. From the method of planking which is adopted, consisting of three thicknesses of oak placed diagonally and longitudinally, the vessel is completely trussed from end to end, and at once combines strength and lightness in an eminent manner. The length of the 'Ruby' was 155 feet between the perpendiculars, (since lengthened,) 19 feet beam, and 9 feet 6 inches depth of hold; she will carry with ease 800 passengers. When launched she drew about two feet of water. Her after-cabin is 33 feet long, and will dine 100 passengers; the ladies' cabin is about 15 feet long, and the fore-cabin 33 feet.

Secondly, her superiority is attributable to her engines, which consist of two 50 horse-power engines (100 horse-power the two), in the making and fixing of which, every care was taken to have them as light and efficient as possible, without endangering their stability; and the calculation of weights and of displacement was so nicely adjusted, that when the whole of the weights were on board, and the vessel equipped for service, her real draught of water, 4 feet fore-end and 4 feet 6 inches aft, was within $\frac{1}{4}$ of an inch of the builder's estimate. The weight of the engines complete with the water in the boiler is exactly 90 tons 5 cwt., being about 18 cwt. to the horse-power; the diameter of the cylinder is 40 inches, length of stroke 3 feet 6 inches, diameter of outer edge of paddle-wheel 17 feet, and length of board 9 feet 2 inches, with a dip of 17 inches with 200 passengers on board; then the speed of the engines is 30 strokes per minute, the pressure of the steam being only $3\frac{1}{2}$ lbs. above the atmosphere. The speed of the piston is therefore 210 feet per minute, the speed of the outer edge of the paddle-board is nearly 20 miles per hour, and the speed of the vessel through still water by repeated trials is exactly $13\frac{1}{2}$ miles per hour.

It is a remarkable fact, that from the first day of trial to the year 1838, the speed of the 'Ruby' did not vary $\frac{1}{12}$ th of a mile per hour; she neither increased nor lost her speed. This is mostly to be attributed to the fact of the engines being in a most perfect state when set to work, but more particularly to the use of the patent slide-valves, and which, after two years' working, were found as perfect upon their faces as when first put together: a further proof of their superior working is evinced by the vacuum in the condensers of the engines having never varied $\frac{1}{4}$ of an inch, remaining constantly between $28\frac{1}{4}$ and $28\frac{1}{2}$. This is ascertained by barometers attached to each engine, which are not affected by the atmosphere, and makes the vacuum as perfect as possible; for supposing the waste water as it leaves the condenser to have a temperature of 110° , which is equal to $1\frac{1}{2}$ inch of mercury, (see Professor Robison's experiments,) when added to $28\frac{1}{4}$ it gives $29\frac{3}{4}$, the usual height of the marine barometer in fine weather.

The safety-valves are arranged upon the plan invented and used by Messrs. Boulton and Watt many years since, and generally adopted by the engineers of London. They are so arranged that no one on board can possibly have access to them; the engine-man can at pleasure open them and let the steam escape, but he has no means by which he can keep them down, beyond the weight placed upon them by the engine-maker, which weight is, as before stated, $3\frac{1}{2}$ lbs. on the inch; and it is a curious fact, that this boat attained the great speed before named with this small pressure, while in a variety of instances vessels from different outports, working with high-pressure steam, and with the safety-valves loaded *ad libitum* by the engineers and captains, were never able to approach her in speed. This clearly proves, what the late Mr. Watt demonstrated long since, that the most efficient, safe, and economical mode of working steam engines for marine purposes is at a pressure of from $2\frac{1}{2}$ to $3\frac{1}{2}$ lbs. on the inch. At the same time, for single-acting pumping engines there is, no doubt, an advantage gained by the judicious use of high-pressure steam, say of 30 lbs. on the inch, working expansively, with boilers properly constructed, but which boilers, for many reasons, are not at all fit for steam vessels; in fact, almost all the melancholy accidents that have occurred to steam-boats by the explosion of their boilers, have been caused by the injudicious application of high-pressure boilers to marine purposes.

It is here worthy of remark, that the Americans, who claim to propel their vessels at the high speeds of 15, 16, and in some cases 18 miles per hour, state that the principal cause of their alleged triumph is owing to the use of high-pressure steam, used expansively; the causing the pistons of very long-stroke engines to move at the rate of 300, 400, and sometimes 600 feet per minute; and lastly, to the superior form of the bows of their steamers, which are built so as to glide over the water instead of cutting through it.

In the case of the 'Ruby,' in all these important matters she is decidedly the reverse of the American vessels; the piston only travels about 210 feet per minute, very low-pressure steam is used, the stroke of the engines is very short, being only 2 inches more than the diameter of the cylinder, and the form of the bow is decidedly that which will cut or divide the water without the least tendency to ride over it, inasmuch as this vessel's bow is shaped like a knife, being as long on the keel as at the water's edge within 2 feet.

REFERENCES.

A, The cylinder.	<i>a a</i> , The steam nozzle and valves.
B B, The sway-beams.	<i>b b</i> , The eduction nozzle and valves.
C, The cross-head.	<i>c</i> , The steam-pipe.
D, Main gudgeon.	<i>d</i> , The throttle-valve.
E E, The side-rods.	<i>e</i> , Handle and rod of throttle-valve.
F, The fork-head.	<i>f</i> , Starting lever.
G, The connecting rod.	<i>g</i> , Spill of steam-valve.
H H, The cranks.	<i>h</i> , Spill of eduction valve.
I I, The shafts.	<i>i i i</i> , Levers for working the valves.
K K, The side-frames.	<i>k</i> , Rod to connect levers.
L L L, The condenser, hot well, and foundation-plate, all cast in one piece.	<i>l l</i> , Parallel motion.
M, The air-pump.	<i>m</i> , Snifting valves.
N, The feed-pump.	<i>n</i> , Blow-through valve.
O O, The sleepers.	<i>o</i> , Eccentric rod.
P, The crank-pins.	<i>p</i> , Eccentric beam and balance.

EXPLANATION OF THE PLATES.

DIMENSIONS.

Speed of the engine		30 strokes.
Diameter of wheel		17 ft. 6 in.
Diameter of the float		17 6
Diameter of cylinder		3 4
Length of stroke		3 6
Weight of engines (two)		80 tons.
Dimensions of boiler	. 18 ft. long, 14 ft. 2 in. wide, and 7 ft. high.	
Length of paddle-board		9 ft. 2 in.
Width of board		15 inches.
Speed through still water		13½ miles.

In 1837, this boat ran four times a day to and from Gravesend during six months, making a distance of 48,600 miles.

She beat Red Rover		10 minutes,
Star		12 „
Mercury		27 „
Vesper		10 „
Diamond		12 „
Gem		5 „

Against tide from Gravesend to London: all other boats from 30 to 60 minutes.

PLATE XXXVI. (Marked, in error, Plate 9.)

DIAMOND COMPANY'S STEAM PACKET 'RUBY.'

This Plate represents a drawing of the 'Ruby' steamer, which belongs to the Diamond Company, plying between London and Gravesend, and is one of the fastest boats on the Thames. It would be entering too much into detail to give a statement of the progressively improving character of the various steam boats which have plied between London and Gravesend during recent years; it is enough for our present purpose to state that the Diamond and Star Companies have kept up an establishment of a very superior description, everything connected with their appointments having been upon a most liberal scale. The vessels belonging to the Diamond Company were, the 'Diamond,' 'Pearl,' 'Gem,' 'Brilliant,' 'Topaz,' and 'Ruby;' and those belonging to the Star Company, the 'Mercury,' 'Star,' 'Comet,' 'Planet,' 'Vesper,' &c.; one of the boats, 'Medway,' having been burnt by accident during the summer of 1837. Until the beginning of the year 1837 (at which time the 'Ruby' was placed on the station), the 'Star' was considered to be equal in speed to any of the above; indeed, it may be said that no vessel that navigated the Thames could equal her, except perhaps the 'Diamond' and the 'City of Canterbury.'

Vessels of the greatest speed will always command a decided preference; hence it is the interest of proprietors to apply to the most skilful naval architects and engineers, to procure vessels which combine speed with strength and durability.

The 'Ruby,' built for the Diamond Company, as before stated, at Blackwall, in the early part

of the summer of the year 1837, possesses the above essential qualities in an eminent degree. Mr. O. W. Lang, who designed the 'Ruby,' has obligingly furnished the lines, and many particulars respecting the vessel.

Her length was 155 feet between the perpendiculars, but has since been much lengthened; 141 feet $9\frac{1}{2}$ inches on the keel for tonnage; breadth for tonnage 19 feet, moulded 18 feet $5\frac{1}{2}$ inches; depth in hold 10 feet 2 inches; and burthen 272 tons. She is propelled by two engines of 50 horse-power each, made by Messrs. Seaward and Co., of which the following are some of the most important particulars:—Diameter of cylinder 40 inches; length of stroke 3 feet 6 inches; number of strokes per minute 30; diameter of paddle-wheel 17 feet 6 inches; length of paddle-board 9 feet 2 inches, and depth 15 inches; dip, or immersion, 15 inches. The practical construction of the vessel is upon a principle recommended by Mr. O. W. Lang, and invented many years since by Mr. Johns, a clever practical officer of Plymouth Dockyard. It consists of an outer surface of plank, placed horizontally in the usual manner, but of $1\frac{1}{4}$ inch only in thickness, the timbers being substituted by two other thicknesses of plank, laid diagonally to the keel, but at right angles to each other, with felt introduced between the layers, the whole three being fastened together by nailing, in the same manner as a clench-work boat. Vessels built in this manner have been found to be far less expensive (at least 20 per cent.) than vessels built in the usual way; they also possess greater strength, and judging from the trials that have been made of ships' launches and other large boats for the Navy,¹ for several years past, there can be no doubt of their durability. The comparative lightness of vessels built in this manner is also a great recommendation. The 'Ruby,' when launched, was found to displace only 65 tons of water. Her draught, with her engines and fuel on board, complete in all respects, was only 4 feet 8 inches abaft, and 4 feet 1 inch forward; her displacement 170 tons, and the area of her midship section 63·2 feet: under these circumstances her speed through the water had been ascertained, previous to her being lengthened, to be 13·5 miles per hour, no other vessel having exceeded the rate of 12·7: since then, the speed of this vessel has much increased.

PLATE XXXVII. (Marked, in error, Plate 20.)

BOILERS OF HER MAJESTY'S SHIPS 'HERMES,' 'SPITFIRE,' AND 'FIREFLY.'

These boilers were constructed by the Butterley Company: they are very compact, light, and efficient, and any two of them may be employed in case of accident to one of them, when the vessel is at sea. Each has its own steam-pipe, which can be shut off at pleasure, its safety-valve, and a damper, which being closed, as shown in the transverse section, cuts off the communication with the chimney. A contrivance is effected by which a man can creep into the boiler underneath the flues to clean or repair it, which has been found very useful: it does not increase the height of the boilers, and adds very little to their weight. The front view of the boilers is placed in a section of the 'Hermes,' to show the 'channels' or passages by which the man has access to the under side of the flues, down between the engine sleepers or foundation timbers.

The cylinders of the 'Firefly' are $43\frac{1}{2}$ inches in diameter, and the stroke is 4 feet 6 inches, which, at

¹ The boats built for the Navy are only of *two* thicknesses, the outer (fore and aft) planking being deemed unnecessary. They are well known as Mr. Johns's double-bottomed diagonal-built boats, and are held in high estimation.

22 revolutions per minute, gives the velocity of piston 198 feet per minute. The area of the piston in square inches is 1486.1, and if the effective pressure be 10 lbs. per square inch, it would make the horse-power $\frac{1486.1 \times 198}{33000} = 89.2$ horses' power. But the speed of the piston is taken at 185 feet, large allowances are made which the present improved state of workmanship perhaps renders unnecessary, and the engines are estimated at $2 \times 70 = 140$ horses' power. This is probably correct for a sea-going vessel, where the engines often cannot work at their proper speed.

PLATES XXXVIII. AND XXXIX.

ENGINES OF HER MAJESTY'S STEAM SHIP 'MEGÆRA.'

Her Majesty's steam ship 'Megæra' is fitted with Messrs. Seaward's engines and Mr. Samuel Hall's condenser.

Plate XXXVIII. represents an elevation of the engines.

Plate XXXIX. exhibits a section of the same engines, and comprises a delineation of Seaward's patent slide-valves, the principle of which has been described in art. 396.

The same letters refer to corresponding parts in both Plates.

A is the boiler, of which—

a is the furnace-door.

a', Grate-bars.

a'', Furnace.

b, Bridge.

c, Flues.

d, Take-up.

e, Chimney, which is surrounded with a double casing e', filled with incombustible and non-conducting matters, calculated to intercept the heat, and thereby prevent accident from fire.

f, Water space beneath the flues, sufficient to permit a free passage for cleaning and repairs.

f', Water space between the flues.

g, Steam-box, on which are fitted the safety-valves g' in close iron boxes g''.

h, the stop valve, fitted on the upper end of the steam-pipe h', so that the steam may be completely shut off from either boiler, and the engines, as found necessary.

B, the steam cylinder, with its piston B'; m m' m'', steam-slide casing, of which the boxes m' m'' contain the steam slides which are connected by the pipe m' with the steam-pipe h' leading from the boiler A.

n n' n'', exhaustion slide casing, the boxes n n'' containing the exhaustion slides, which are connected with the top chamber of the condenser L, by the exhaustion pipe n' and the nozzle at n.

Both the steam and exhaustion slide casings are cast on the cylinders, due consideration being paid to the difference in expansion and contraction of the side pipes m' n', and of the cylinder B.

By this construction, the usual joints at the nozzles, 1, 2, 3, 4, by which the slide casings are attached to the cylinders, are dispensed with, and of course the risk of leakage avoided.

rr, ss, are the steam-slide facings or back-plates, through which are apertures corresponding with those of the nozzles 1 and 2.

tt, vv, are the exhaustion slide facings or back-plates, the apertures through which correspond, in like manner, with those of the nozzles 3 and 4.

The four back-plates, *r, s, t, v*, are distinct from the casings, and are fixed in the boxes or recesses *m m'', n n''* of the slide casings, by folding wedges or keys, so that *r r, s s* have their backs against the cylinder, while *t t, v v* present their faces to the same, their backs being wedged to projections or flanches adapted thereto in the recesses *n n''*.

To insure perfect joints, a plain caulking space is left at the bottom and back of each slide-face, while the edges, which fit the casing at the face, have dovetail portions removed so as to permit the insertion of soft or elastic packing, which, with that beneath and at the back, completely surrounds the aperture and renders all tight.

Facility is afforded of removing either back-plate when requisite, by driving back the folding wedges or keys, which keep them firmly in place, this dovetail form of the edge permitting the facings to be readily detached from the packing after being pressed by the wedges.

w, x, y, z, are four slide-valves, of rectangular figure, receiving their motion from rods or spills passing through the stuffing-boxes 5, 6, 7, 8.

The valves *w, x* are the steam-slides, having their backs always presented to the steam from the boiler, which maintains them in close contact with the faces of the back-plates *r r, s s*.

The valves *w, x*, it will be seen, are connected to their rods or spills by knuckle-joints, so as to permit perfect freedom of motion off their facings, independently of the rods. By this contrivance, water carried over from the boilers into the cylinder is forced back by the piston into the steam-pipe *h'* till drawn off by cocks fitted at the bottom for such purpose; thus obviating the risk of accident from its accumulation, and dispensing at the same time with the necessity for escape or discharge valves.

The backs of the exhaustion valves *y, z*, being alternately submitted to the pressure of the steam on the descent and ascent of the piston, while their faces are presented to the condenser, it will be observed that perfect contact of the slides with their back-plates *t t, v v* will ensue.

Thus the four slides *w, x, y, z*, are caused to operate without packing, and without being submitted to greater friction than that due to the simple pressure of the steam.

ACTION OF THE VALVES.

The steam passing from the boiler A, by the steam-pipe *h'*, is regulated in its admission to the slide-valves *w x*, by the throttle-valve *i*, the rod *j j*, with its lever *j'* and adjusting arc *j''* being conveniently adapted for the same.

The engine, then, after being cleared of air, &c. through the blow-valve *l*, is put in motion by means of the starting lever *p'*, and causes the eccentric O, through its rod *o'*, to actuate the lever *p* of the exhaustion balance-shaft X, a system of levers *q q* affording the means of engaging and disengaging the same, according to the necessity of reversing or stopping the wheels. And the shaft X, being connected with the balance-shaft Y of the steam-slides by the levers *u u'*, and the rods *u''*, it is clear that both shafts will operate simultaneously on all four slide-valves, which are connected to the levers *u u'* of the said shafts by the side-links 9, 10, 11, 12. Now when the lever *p* is urged by *o'*, from the condenser L, the steam-slides *w, x* will be caused to descend, admitting the steam above the piston B' through the passage No. 1, while No. 2 will be closed by the slide *x*. The exhaustion slides *y, z*, ascending at the same time, will permit the steam from beneath the piston to pass off, through the passage No. 4 and pipe *n'*, into the condenser, the passage 3 being closed by the slide *y*.

When the lever *p*, on the contrary, is drawn towards the condenser L, the exhaustion slides will be depressed, while the steam-slides are caused to ascend, thereby reversing the operation of the steam.

The lever *u*, moreover, which gives motion to the steam-slides, is so contrived that the extremity of the rod *u''* can be moved by an adjusting screw through a considerable space in a slot seen at *u*, thereby lengthening and shortening the leverage, and consequently the stroke of the steam-slides.

The steam is thus caused to act expansively, to such extent as the variable circumstances of the weather at sea may suggest, the advantages of which are shown in arts. 367, 396, and elsewhere.

Hall's condenser is shown at L, of which 13 is the upper chamber, containing a thin plate 14, completely perforated with small holes, by which the steam from the cylinder B is distributed in its passage through the pipes 15, 15, to the bottom chamber, 16.

The pipes 15, 15 are surrounded with cold water, which is supplied through the pipe R', by the double-acting pump R R', whose motion is derived from the main lever C, through the rods W T, and the lever U, which is supported by the bracket V; the waste water passing into the sea through the opening S.

M is the air-pump, through which the bucket M' discharges the water resulting from the condensation of the steam from the cylinder, in its passage through the pipes 15, 15, together with the air and uncondensed vapour, into the hot well Z, through its valve 17, whence it is carried forward by the feed-pipes into the boiler A.

Still, in order to meet unavoidable losses of water from the boilers by the waste of steam, &c., a distilling vessel A', of cylindrical figure, is introduced within the boiler, which uniformly maintains the requisite height of water therein, in the following manner:

A pipe, 18, connecting the upper surface of the still A' with the upper or steam chamber, 13, of the condenser, is furnished with a stop-cock 19, which when open permits the vapour generated in the still to pass over into the condenser, whence it is returned by the feed-pipes, in addition to the water resulting from the steam of *exhaustion*, into the boilers, and is regulated in quantity by the amount of opening of the stop-cock 19.

The connection with the condenser produces a nearly corresponding vacuum in the still, whence evaporation takes place at a lower temperature and much more rapidly than if exposed to the atmosphere at the ordinary boiling point of 212° .

As the evaporation proceeds, and the water in the still becomes lower than the level marked in the drawing, the copper float 20 descends, carrying with it the rod 21 of the index 22, and causing the valve 23 to be lifted at the same time. The valve 23 being connected with the supply-pipe 24, which is joined at the other extremity with the waste-pipe S of the condenser, affords abundance of sea water to pass into the still, until again closed by the float 20; the index 22 exhibiting the operation.

By the frequent repetition of this process it will be seen that the water in the distilling vessel A' will become saturated with salt, and in that respect the still will be assimilated, with the exception of risk from burning in case of neglect, to ordinary boilers working with sea water: it is also kept clean by the same rule, thus:

The pipes 18 and 24 being first shut off from the still by their respective stop-cocks, a communication is opened by the cock 25 with a pipe 26, which descends nearly to the bottom of the still, its other end passing through the ship's side. At the same time, another pipe (not seen), also furnished with a stop-cock, allows the steam from the boiler to pass into the upper part of the still, whence by its pressure the brine and other impurities are completely driven out into the sea.

These latter pipes being shut off and the former ones opened, the process of distillation goes on as usual.

The piston B', acting on the cross-head D, gives motion to the side-rods E, which are connected at the lower ends with the beams or main levers C, and these vibrating on their axes C', transmit the motion to the connecting rod G, through its side-links or forks H, and fork-head F.

The crank I, being impelled by the upper end of the connecting rod, produces a rotary motion about the paddle-shaft N, which is supported by the framing K K.

The air-pump bucket M' receives its motion through the cross-head P and side-rods Q, which are connected to the beams at Q'.

To maintain rectilinear motion of the piston-rod, a perpendicular rod 27, from the beam C, is caused to act on the radius crank 28 and parallel rods 29, whose action is transmitted to the piston through the side-rods E, as in the other parallel motions.

PLATES XL. XLI. XLII. AND XLIII. (Marked, in error, Plates 10, 11, 12, and 13.)

ENGINES OF THE HULL AND LONDON PACKET 'WILLIAM WILBERFORCE.'

Plate XL. represents a plan of the engines of the 'Wilberforce' Hull and London packet, built by John and Edward Hall, of Dartford, and fitted with Samuel Hall's patent condensers, and Francis Humphrys's patent slides. The mechanical arrangement of these engines differs from other marine engines provided with Hall's condensers, as every part of the condensing apparatus is fixed on the foundation plates of the engines, and the cold-water pumps receive their motion directly from the great levers, by means of side-rods and cross-heads, like the air-pumps, by which arrangement the parallelism of the several rods employed in working the cold-water pumps is preserved, and the pumps themselves firmly and substantially fixed and united with the several other parts comprising the engines; thus also affording every convenience for ready access to the valves or plungers in case of their requiring repairs.

The slide-valves of these engines, as well as the pistons and air-pump buckets, are wholly metallic, and their operations have proved them to be quite as efficient as D slide-valves in their most perfect condition, without requiring any care or attention from the engineer; and they work with so little friction, that one man can, when required, handle both engines, although the leverage power, as will be seen by inspecting the engravings, is little more than as two to one: this affords a great advantage to a marine engine, particularly in a crowded river like the Thames; but their more important advantage is felt in the steady maintenance of the power of the engines, and in the economy of fuel arising from the total absence of the leakage common to all hemp-packed slide-valves when neglected by the engine-man, or not plentifully supplied with melted tallow.

The general operation of these engines is like that of all other marine engines fitted with Hall's condensers, excepting that the water pumped from the condensers by the air-pumps is not forced by the air-pumps through the feed-valves directly into the boilers, but is delivered into a casing or cylindrical jacket surrounding the chimney, and flows out at the upper part of the casing, into a stand-pipe, sufficiently high to retain a column of water to overcome the pressure within the boilers, like the usual mode of feeding boilers in an ordinary Boulton and Watt engine. By this means the water acquires an additional temperature of about twenty degrees before it enters the boilers, and it is more perfectly separated from any bubbles of air which may arise in admixture with the water when it leaves the air-pumps.

The nominal power of these engines is 285 horses'; a very rapid and perfect exhaustion of the cylinders is effected. The advantage of Samuel Hall's process of condensing by contact instead of by injection, is, that in a heavy sea, while the vessel is rolling and exposed to the effects of half a gale of wind, the vacuum is as perfect as in smooth water, and the exhaustion of the cylinder,

proved by actual experiment, amounts to 13 lbs. upon each square inch of its area, which, together with the pressure of the steam, gives a mean force on the piston of 16.54 lbs. per square inch, and produces an absolute effect of 283.6 horses' power, or 567.2 horses' power with both cylinders, after deducting 2 lbs. per square inch on the pistons for the friction and power expended in working the pumps, &c., leaving an effect of 98 per cent. more than the nominal power of the engines.

The uniform velocity of the engines in smooth water is 22 revolutions, the pistons moving through 264 feet per minute when the draught of the vessel is 9 feet 6 inches forward and 11 feet aft, at which draught the paddle-wheels are immersed 3 feet 6 inches, measuring from the outer edges of the centre floats to the surface of the water, and the total area of the paddle-boards, thus immersed, amounts to 102 feet in each wheel.

The same letters of reference are employed to denote the same parts in each engraving, the use and operation of which will be understood on referring to the several Plates.

Plate XLI. represents a cross section, showing the after parts of the engines and the paddle-wheels.

Plate XLII. represents a longitudinal elevation of the engines.

Plate XLIII. shows a longitudinal section of the engines.

A, Steam-pipes.

B, Throttle-valves for regulating the supply of steam to the engines.

C, Blow-valves for clearing the engines of air, by the admission of steam previous to starting.

D, Inlet sluices and pipes, 11 inches diameter in the clear, for admitting the supply of water to the cold-water pumps.

E, Relief valves for the purpose of affording a ready escape for any accidental accumulation of water within the cylinders, either below or above the pistons.

F, Humphrys's metallic slides, by which the great pistons are actuated.

G, The cold-water pumps for forcing the water into the condensing cisterns H: these pumps are 18 inches diameter, having a stroke of 2 feet 8 inches, and supposing their chambers to be quite filled with water at each stroke, will supply at the rate of 8 gallons of water per minute per horse-power, which is forced round the lower extremities of the condensing pipes, and, ascending amongst them with considerable velocity, escapes through apertures in the cisterns at their upper extremities, by the pipes marked L.

H, Condensing-cisterns; each cistern containing 2374 half-inch copper pipes, 8 feet long each between the top and bottom plates, in which their ends are fixed, thus giving a total length of 18,992 feet of pipe to each condenser exposed to the cold water, which is equivalent to $\frac{18992 \times 2}{285.4 \text{ H. P.}} = 133$ lineal feet of $\frac{1}{2}$ -inch pipe per horse-power.

I, Air-pumps, 35 inches diameter and 3 feet stroke, by which the water and air are pumped out of the condensers and conducted by the pipes K to the casing or jacket surrounding the chimney, where it is warmed and perfectly separated from the air, and descends through a stand-pipe into the boilers by its hydrostatic pressure, as usual in the ordinary mode of feeding low-pressure boilers.

K, The feed-pipes, 4 inches diameter: each pipe is provided with a stop-valve to prevent the water returning from the casing around the chimney into the air-pumps.

L, Outlet pipes, 11 inches diameter in the clear, through which the water from the condensing cisterns is conducted outside of the vessel.

M, Bilge-pumps.

O, Starting-handles for working the slide-valves.

PLATES XLIV. XLV. XLVI. AND XLVII. (Marked on Plates, 1, 2, 3, 4.)

TEN HORSE-POWER ENGINE, CONSTRUCTED BY W. FAIRBAIRN AND CO.

Plate XLIV.	Fig. 1. Elevation of engine.	} The letters refer to the same parts in all the views.
XLV. {	2. Plan of ditto.	
	3. Sectional plan.	
XLVI.	4. Cross sectional elevation.	
XLVII.	5. Sectional elevation.	

A, Engine base.
 B, Column or pillar, to support the end of crank-shaft.
 C, Crank-shaft.
 D, Fly-wheel.
 E, First motion spur-wheel.
 F, Steam-pipe from boiler.
 G, Stop-valve.
 H, Cylinder.
 I, Belt round the cylinder, to bring the steam into the valve-case.
 K, Slide-valve.

L, Steam-ports.
 M, Piston.
 N, Eduction pipe.
 O, Feed-pump.
 P, Feed-pipe.
 Q, Water-cock.
 R, Clack-valves of feed-pump.
 S, Connecting rod.
 T, Eccentric, for working the slide-valve.
 U, Eccentric rod for ditto.
 V, Governor-wheels.
 W, Governor.

PLATES XLVIII. XLIX. AND L. (Marked on Plates, 5, 6, 7.)

FORTY-FIVE HORSE-POWER ENGINE, CONSTRUCTED BY W. FAIRBAIRN AND CO.

Plate XLVIII.	Fig. 1. Elevation of engine.	} The letters refer to the same parts in all the views.
	2. Plan of ditto.	
XLIX. {	3. Front elevation.	
	4. Back ditto.	
L.	5. Cross section.	

A, Base-plate of engine and condenser.
 B, Steam-cylinder.
 C, Column and hot well.
 D, Cut-off valve, and steam-pipe from boiler.
 E, Slide-valve casing.
 F, Slide-valve.
 G, Steam passages.
 H, Metallic piston.
 I, Passage to condenser.
 K, Condenser.

L, Air-pump.
 M, Foot-valve.
 N, Air-pump bucket.
 O, Discharge valve.
 P, Waste-water pipe.
 Q, Injection pipe and regulating valve.
 R, Force-pump.
 S, Solid plunger of force-pump.
 T, Beam.
 U, Piston-rod.

V, Air-pump rod.	<i>g</i> , Lever for counterbalance-weight.
W, Force-pump rod.	<i>h</i> , Boot-leg for giving motion to the slide-valve.
X, Connecting rod.	<i>i</i> , Slide-valve rod.
Y, Crank-shaft.	<i>k, K</i> , Counterbalance-weight of slide-valve.
Z, Toothed fly-wheel, forming first motion-wheel.	<i>l</i> , Stud on small wheel for giving motion to the rod <i>m</i> .
<i>a</i> , Governor-wheels.	<i>m</i> , Rod for working cut-off valve.
<i>b</i> , Governor.	<i>n</i> , Vibrating shaft for ditto.
<i>c</i> , Wheels for working cut-off valve gearing.	<i>o</i> , Lever on shaft <i>n</i> for working cut-off valve.
<i>d</i> , Eccentric rod for working slide-valve.	<i>p</i> , Rod with regulating screw, and levers for ditto.
<i>e</i> , Socket for the starting-handle.	
<i>f</i> , Vibrating shaft to work slide-valve.	

PLATE LI.

This Plate represents a plan and section of boiler-seating for a twenty-horse engine, at the manufactory of Messrs. Whitworth and Co., Manchester.

PLATE LII.

This Plate represents Messrs. Hague's double-acting cylinder, with slides, &c.

Fig. 1 is the cylinder, showing the facings for slide; A is the passage to the top; B the passage to the bottom; and C the exhausting passage.

Fig. 2 is a section of the cylinder and slide in the position for letting in the steam at the top A, and exhausting at the bottom through B C; D is the slide with the exhausting passage through it; F is a spring to keep the slide to its face; and G the steam-pipe from the boilers.

Fig. 3 shows the facings of the slide.

Fig. 4 shows the side of ditto.

PLATES LIII. AND LIV. (Marked on Plates, 14 and 15.)

SECTIONS OF THE ENGINES OF THE HON. EAST INDIA COMPANY'S ARMED STEAM VESSEL 'BERENICE,' MANUFACTURED BY ROBERT NAPIER, ESQ., OF GLASGOW.

A A, Boilers.	H, Framing.
B, Steam-pipe connected to jacket of cylinder.	I, Steam-chest for containing D slide-valve.
C, Cylinders.	J J, Eccentric rod and gearing for connecting and disconnecting engines.
D, Bed-plates of engines, with condenser, hot well, &c., cast in one piece.	K, Piston-rod.
F, Hot well.	L, Cross-heads.
	M, Cylinder side-rods.

N, Parallel motion.	<i>g</i> , Expansion valve shaft.
O, Side-beams (or side-levers).	<i>h h</i> , Gear for working expansion valve.
P, Air-pump side-rods.	<i>i</i> , Side-rods for working parallel motion.
Q, Connecting rods.	<i>j</i> , Waste-water pipe.
R, Main cranks.	<i>k</i> , Injection pipe.
S, Intermediate shaft.	<i>l</i> , Waste-pipe from feed-pump.
TT, Paddle-wheel shafts.	<i>m</i> , Pump for filling boilers, washing decks, or extinguishing fire: the pump may be worked by the engine or crew.
U, Paddle-wheel.	<i>n</i> , Steam-pipe.
V, Paddles (or floats).	<i>o</i> , Feed-pipes for boilers.
W, Plumbing-blocks.	<i>p</i> , Feed-pump.
X, Waste-pipe from top of hot well.	<i>q</i> , Cast-iron crank-hatches.
Y, Stays for binding engines together.	<i>r</i> , Malleable-iron stays for supporting ends of paddle-beams.
Z, Eccentric pulley.	<i>s</i> , Malleable-iron knee and stays for supporting ends of beams.
Nos. 4 4 4, Engine bearers.	<i>t</i> , Handle for working pump on deck.
5, Keelson.	<i>u</i> , Funnel.
6, Keel.	<i>v</i> , Steam-chest.
<i>a a</i> , Safety-valves on top and bottom of cylinder.	
<i>b</i> , Stuffing-box on cylinder cover.	
<i>c</i> , Valve-shaft.	
<i>d</i> , Parallel motion shaft.	
<i>e</i> , Starting shaft.	
<i>f</i> , Hand-gear for starting engines.	

The engines are 250 horse-power, and the following are the principal dimensions:

Diameter of cylinder		4 ft. 8 in.
Length of stroke		5 6
Diameter of wheels		23 0
Length of paddle-boards		8 6
Breadth of ditto		2 1
Diameter of funnel		4 0
Length of funnel above deck		36 0

PLATES LV. AND LVI. (Marked on Plates, 16 and 17.)

THE HON. EAST INDIA COMPANY'S STEAM VESSEL 'BERENICE.'

This beautiful vessel, which is of 680 tons, was built on the Clyde; and her engines, 230 horse-power, were manufactured by Mr. Robert Napier, of Glasgow.

EXPLANATION OF THE PLATES.

From the log of her voyage from Falmouth to Bombay by the Cape of Good Hope, performed between the middle of March and the middle of June, 1837, the results expressed in the following Table have been derived :

Voyage performed.	Distance, in nautical miles.		Time occupied, in days and hours.	Rate per hour, in miles.		Coal expended.		Oil expended, in gallons.	Tallow expended.	Work of a ton of coals, in miles.
	Mea-sured.	By log.		Measured distance.	Log. distance.	Tons.	Cwts. per hour.			
Falmouth to Tene-riffe }	1430	1572	d. h. 7 7	8·2	8·9	127	14·5	124	380	11·2
Teneriffe to Mayo B. Vista . . . }	840	952	4 9	8·0	9·0	84	16·2	17	240	10·0
Mayo B. Vista to Fernando Po . }	2180	2272	11 5	8·1	8·4	155	11·4	39	1770	14·1
Fernando Po to Cape Good Hope }	2340	2594	14 5	6·8	7·6	267	15·6	52	1614	8·1
Cape Good Hope to Mauritius . }	2290	2692	13 0	7·3	8·6	246	16·2	48	578	9·3
Mauritius to Bom-bay }	2520	2847	13 18	7·6	8·6	197	11·9	55	—	14·4

The boilers, three in number, are of copper ; they are blown out every two hours. There is no gauge on the steam-chest, or for the steam ; and there are nine fires. The wheels, which are of the common kind, are about 22 or 23 feet in diameter, and the boards 9 feet wide. The cylinder is 56 inches, and the stroke 5 feet 6 inches.

Plate LVI. presents a view of the vessel at sea, off Bombay ; Plate LV. showing the sheer draught, lines of bottom, &c.

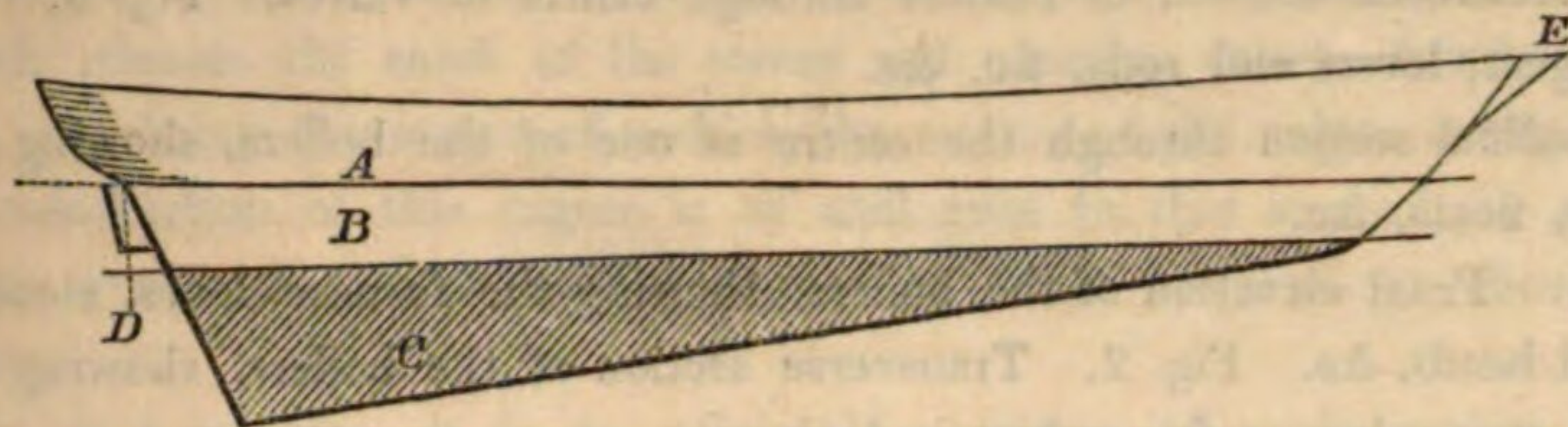
GENERAL OBSERVATIONS UPON THE CONSTRUCTION OF STEAMERS.

The construction of the draught should be made with very strict attention to the weight of the hull, fittings, stores, engines, coals, and cargo (if required to take goods), reducing as much as possible the component parts of the hull, and giving that form which is best adapted for velocity.

It should be particularly considered, as stated by Sir Robert Seppings, that the strength of any fabric consists in the disposition of the materials (in the connection and security of its several parts), and that "*the strength of a vessel, let its construction be what it may, can never exceed that of its weakest part ;*" or that "*union is strength,*" *i. e.* giving the required strength with the least quantity of wood, copper, iron, &c. ; keeping every part of the fabric as tight as is consistent with safety, equal to contend with the violent action and impulse it will be subject to at sea. The fastenings recommended (and which have been so extensively introduced) are those laid down in 'The New Principle of Ship-Building,' by Sir Robert Seppings,—a system of trussing and diagonal ties of iron. (*Vide* the Philosophical Transactions.)

The form should be, in midships, nearly a square, with the corners rounded off, or 'a long, flat floor,' gradually rising to an acute angle at the extremes, or fore and after bodies, similar to the water-lines or horizontal sections of those renowned and celebrated schooners of America, called

'Clippers;' the dead-wood or extreme fineness abaft being dispensed with, as shown in the following diagram :



A, The water or horizontal *load* line.

B, The new line of keel, the dead-wood shown by the shaded part to be dispensed with.

C, The old line of keel.

D, The new line of post, with the rake taken out and brought perpendicular to the new line of keel, *B*.

E, The stem to have a flare or flam to correspond with the bow.

To prevent rolling as much as possible and falling to leeward, two deep bilge-keels to be fastened to the bottom plank, with bolts clenched on the inside. (These keels have been well tested in certain vessels belonging to the Honourable East India Company, in Bengal.)

The fore and after bodies of the American schooners (applied as just described) have been proved to be the best suited for velocity, the sharp flaming bow dividing the fluid with the greatest facility, and the fineness of the run allowing it to pass to the stern with the utmost rapidity.

This improved form is obtained by giving a great proportion of length to breadth, which has been so successfully adopted in the building of all recently constructed steamers (particularly those built for private companies or individuals). In the translation of Chapman's celebrated work by Dr. Inman it is said—"Care must be taken to shape the fore and after bodies, the former so that the fluid may be cloven with facility, and at the same time the displaced fluid dispersed and transmitted towards the stern with as much ease as possible." Velocity in steam vessels is, therefore, obtained by a light draught of water, and keeping the fore and after bodies sharp, and giving the least proportion of length to breadth with reference to the *required* stability, viz.: for sea-going steamers, six times the breadth for the length at the load-water line; in vessels for inland or river navigation, the length has been carried to ten times the breadth in some of the American boats.—*Vide* Stephenson's work on American Engineering.

PLATES LVII. LVIII. LIX. LX. AND LXI.

SIXTY-FIVE INCH CYLINDER ENGINE, ERECTED BY MESSRS. MAUDSLAY, SONS,
AND FIELD, AT CHELSEA WATER-WORKS, 1837.

The drawings in these Plates are as follow :

Plate LVII. Elevation of the engine-pumps and air-vessel.

Plate LVIII. Longitudinal section through the centre of the cylinder, nozzles, beam, main pump, &c.

Plate LIX. Fig. 1. Front elevation of the hand-gear, levers, and rods, with expansion tappet, &c.

Fig. 2. Transverse section of nozzles through centre of valves. Fig. 3. Side elevation of the hand-gear, levers and rods, &c. &c.

Plate LX. Longitudinal section through the centre of one of the boilers, showing the steam-boxes, feed-heads, floats, &c.

Plate LXI. Fig. 1. Front elevation of the boilers, showing the furnace-doors, steam-boxes, damper-pipes, feed-heads, &c. Fig. 2. Transverse section of the boilers, showing the steam-boxes, pipes and stop-valves, safety-valves and pipes.

REFERENCES TO THE DRAWING, PLATE LVII.

A, Cylinder.	L L, Cranes for raising cylinder and pump-covers.
B B B, Nozzles and valves.	M M, Catch-pins.
C C, Condensing cistern.	N, Cold-water pump.
D, Air-pump.	O O, Hot-water pump and air-vessel.
E, Eduction pipe to condenser.	P, Pump-rod.
F, Expansion tappet.	Q Q, Well.
G, Damper barrel for regulating the valves.	R, Working barrel of main pump.
H, Main beam.	S S, Clack barrels.
I, Sliding counterweight.	T, Air-vessel.
K, Hoisting beams.	V, Main pipe.

This engine is single-acting; the diameter of the cylinder is sixty-five inches, and the length of stroke eight feet; the diameter of the working barrel of the main pump is twenty-five inches and the length of the stroke also eight feet.

The boilers are six feet wide, eight feet high, and twenty-five feet long.

The operation of this engine and its appurtenances being nearly similar to the action of other engines before described, it is scarcely necessary to advert to it but for the purpose of explaining that its effective action is only in one direction, viz., during the descent of the cylinder piston. It may be explained as follows:—The progress of blowing through¹ being accomplished, the three valves² shut again, and the injection cock opened, the steam and induction valves are also opened, the former to admit the steam from the boiler into the top of the cylinder, and the latter to permit its egress from the bottom of the cylinder to the condenser. The equilibrium valve remaining shut, the pressure of the steam acting above the piston, with the vacuum underneath it, is sufficient to move the piston, and as it approaches the end of the stroke, or bottom of the cylinder, the hand-gear tappets and catches operate, first to shut the steam-valve, secondly the eduction valve, and lastly, when at the bottom of the stroke, to open the equilibrium, and thus open the communication

¹ Opening the valves for the steam to pass from the boiler into the cylinder and through the nozzles to the condenser, and thus expel the air, vapour, and water through the blow-valve and valves of the air-pump.

² Nozzles in front of cylinder; upper steam-valve; centre equilibrium valve; lower eduction valve.

between the top and bottom of the cylinder; the counterbalance at the outer or pump end of the beam then exerts a force sufficient to move the piston up again, and transfer the steam from the top to the bottom of the cylinder, when the lower tappet shuts the equilibrium valve, and the action of its catch releases the catch of the steam and eduction valves, thereby admitting of their opening as before, and being the means of making the motion of the engine continuous.

The general construction of this engine is so analogous to that applied for pumping-engines in water-works of late years, that it is only necessary to direct attention to those parts which are particularly striking.

Viewed merely as a machine, it is an admirable specimen of workmanship. The beam, and many of the parts, exhibit great strength, and are fully equal to the application of the expansive principle of working, should the adoption of it at a future period be determined upon. The castings throughout are of a superior description, and the fittings and bright work exhibit an attention to detail that cannot fail to attract the notice of the mechanic; he will perceive that the lathe and planing-machine have lent their aid to all the bearing surfaces, and that every care has been taken to insure solidity of construction.

The boilers are of wrought iron, upon the marine principle, securely stayed, and fitted with safety-valves, feed-pipes, and the usual apparatus, with the addition of whistle-pipes—that old but effectual mode of making known the deficiency of water in the boilers.

Arrangements have been made to cover the boilers, steam-pipes, and cylinder with non-conducting substances, as soon as the works are proved.

The structure of this engine admits of its being worked to the various altitudes required for street supplies, the chief means of regulation being the expansion tappet and safety-catch, the latter acting when the length of the stroke exceeds the proper limit. The counterweight for adjusting the engine moves between guide-strips inside the beam; it is worked by a long screw, which (the cross handle being moveable) admits of the whole range of the weight between the catch-pins when the engine is at work.

The main pump and clack-seats are fixed in a very substantial manner; they are supported by four strong iron beams, (through which very large holding-down bolts pass,) and they are steadied by iron plates fixed above and forced against the masonry. The supporting beams are fixed within four feet of the bottom of the working barrel, and the masses of stone above them are considerable.

The pump-clacks are of gun-metal, fitted with wrought-iron plates leathered; these are of large dimensions compared with the working barrel, and they are fixed in separate chambered seatings and held fast by distinct rods pressed down by set-screws.

Duplicates of such of the parts as are liable to derangement are kept in readiness, powerful cranes and hoisting girders are fixed, and the various tools so arranged that the taking to pieces and refixing any part of the engine and pump can be effected without loss of time.

The engine is calculated to raise 2250 gallons of water per minute.

PLATES LXII. LXIII. LXIV. AND LXV. (Plate LXIII. wrongly marked Plate 26.)

DESCRIPTION OF HER MAJESTY'S STEAM VESSEL OF WAR 'MEDEA,' CONSTRUCTED AND BUILT BY OLIVER LANG, ESQ., MASTER SHIPWRIGHT, ROYAL DOCKYARD, WOOLWICH,

Showing the mode of putting her frame together so as to obtain and produce the greatest combination of strength in connecting the various parts of the ship, and distributing the fastenings equally throughout the fabric.

		Light.	Deep.
		Feet. In.	Feet. In.
Draught of water	{ afore	7 0	13 10
	{ abaft	9 1	14 6
Displacement in tons		502·81	1230
Area of midship section		168·84	354

The keel was made secure on Mr. Lang's principle of the 'safety-keels;' the inner or solid one fitted to the floor-timbers in midships, and to the dead-wood afore and abaft, with dowels on the upper or faying part, connecting the floors, dead-wood, and keel together; the under side of the keel projecting a few inches only beyond the bottom, protected by a longitudinal piece of timber, fitted all fore and aft on each side, substituting the chocks usually brought on the heels of the timbers, to fashion them at that place, and of sufficient size not only to make good the said chocks, but likewise the plank of the bottom (commonly called the garboard) in one solid substance: these pieces are placed one on each side of the inner keel, with felt between the faying surfaces, dowelled and connected together by bolts, driven athwartships through all and clenched on a ring at the outer sides of the longitudinal pieces, and likewise in an up-and-down direction, through the frame timbers, similarly clenched: the inner or solid keel, as before described, is previously dowelled and bolted in a vertical direction through the floors, dead-wood, and keelson, in addition to the longitudinal pieces or side keels, the ends of the bolts being well clenched on rings, thus making the base of the fabric perfectly secure and strengthening the most important part of the ship.

The timbers composing the frame of the lower part of the ship are strengthened by solid fillings caulked and made water-tight from the keel to about four feet above the turn of the bilge, so that if the vessel should by accident at any time take the ground, and disturb the outer or false keel with such part of the planking on the lower part of the bottom as might by any possibility come in contact with the rocks, yet she would be perfectly safe, as the inner or solid keel could not be removed, but only ground away in such places as bore against the shore, it being firmly attached to the fabric.

The lower part of the stern-post (vide Plate LXII.) is united to the after-end of the solid keel by a knee-piece scarphed and grooved at the after-end, and scarphed and dowelled at the fore-end, bolted through and securely clenched on a ring at the end of each bolt, instead of the old method, a mortise and tenon, as generally adopted by ship-builders in this and all other countries, which insufficient mode has caused the loss of many vessels. The lower piece of stem is scarphed to the foremost piece of keel horizontally, and not with a vertical or side scarph in a square boxing,—that dangerous system so long practised in vessels of all descriptions,—but, on the contrary, forming no

projecting butt, to the fore-end of the keel: should the gripe be carried away by the ship striking the rocks, the remaining surface of the keel and bottom would offer no resistance to the cable after such an accident, but would retain a similar shape to the original form of the ship when in its perfect state.

The whole frame is connected together by iron braces on the inside, placed in a diagonal direction, let into the timbers about half their thickness, and having one bolt passing through every timber for their security, and a wood trussing of four-inch plank in the opposite direction, to prevent the hull of the vessel from hogging or altering her form: between the wood trussing, the timbers are covered by board of one inch and a half thick, secured at the ends on a cant two inches square, so that the board may bear only on the cants, and allow a current of air to pass throughout the ship.

The upper deck beams are secured to a shelf or thick clamp, which extends all fore and aft on both sides of the ship and embraces every timber; the beams are dowelled and bolted to the said clamp, their ends extending without over the top-side to connect the sponcing, being scored and let into the sponcing timbers, dovetailed, and bolted in a fore and aft direction; a thick strake is then worked on the outside on the ends of the beams against the timbers, forming a sheer strake, scored half-way between the said timbers to meet the thick water-way, which is scored in like manner to meet the sheer strake from inside; felt is placed between the joint vertically, the whole bolted together with bolts driven horizontally and well clenched on a ring at each end; the under side of the water-way is scored dovetail about one inch and a half over the beam; on the upper part of the sheer strake and water-way, felt is laid, and on that a plan-sheer or gunwale placed, which is bolted through the water-way and plan-sheer in a vertical direction, and clenched with a ring on each end of the bolt to keep it down and make it firm. The sponcing timbers run up to the rough tree-rail, their heels stepping on a thick strake worked in the side of the vessel and well bolted, forming a rabbet which receives the planking, making a secure artificial topside in addition to the common topside of the ship.

The engine bearers are dowelled and bolted firmly through the bottom, scored on the under part to receive the nuts for securing the hold-down bolts which prevent their passing through the outside plank and creating danger.

Plate LXIV. shows the plans of the upper and lower decks, under which there is a fore and after platform, exclusive of her store-rooms and magazine; on these platforms there is provision made for berthing in hammocks 145 men in addition to her ship's company, which are berthed in like manner on the lower deck, the fore side of the engine-room; on the aft side the officers' cabins are shown; the planks of the lower decks, both afore and abaft, are laid athwartships, rabbeted into the sides of the beams, which are considerably less in number than if the deck were laid in a fore-and-aft direction on beams, as usually done; the beams are secured to the side by iron knees.

The upper deck is laid in a fore-and-aft direction on substantial beams, made particularly strong on the fore and aft parts with carlings well pillared under the deck in wake of the great guns, which are both of 10 inches calibre, and worked on a carriage and slide with pivots, which admits of their being turned in any direction that may be required; the bulwarks above the plan-sheer are light, the fore and aft parts fitted to drop in several pieces by iron stanchions, forming a hinge, so that the whole or any part required can be let down clear to admit of the guns being run well out, that their muzzles may not interfere with the side of the ship when firing.

Her tiller is under the upper deck, that it may not obstruct the working of the guns; an iron plate is attached to the head of the rudder, with three holes, one in the centre and one on each quarter; an iron plate is fitted on the head of the stern-post, and when the rudder is required to be secured in midships, a pin is dropped into the centre hole of the plate on the rudder, which passing through this and the plate

on the post, fixes the rudder immediately in midships: the same may be done by removing the pin to one of the other holes, when the rudder may be placed on the quarter on either side, if at any time it may be required to lay the ship to, to shift the tiller, or to reeve new ropes to the wheel. The heel of the mainmast is fitted in an iron crutch with a strong pillar, in order to bring the mast nearer its proper position for sailing, which otherwise would be prevented by the boilers.

In corroboration of the foregoing facts, a most extraordinary circumstance may be mentioned. Her Majesty's frigate the 'Pique,' of 36 guns, built with Mr. Lang's safety-keels, had the misfortune to run on the rocks near the strait of Belle Isle, on the 22nd of September, 1835, and tore off her false and likewise her outer main keel all the way fore and aft, and ground away, in four different places, the inner or solid keel, and the longitudinal pieces at those parts forming the garboard connected thereto, which, being so firmly attached to the ship, bore the violent friction of such ponderous weight,—the frigate with her guns, stores, &c.,—in contact with the rocks, without being displaced; and the vessel was got off, preserved from shipwreck, and brought to England in safety, although encountering very severe gales of wind on her passage. Several instances have occurred of other ships fitted with the safety-keels getting off the rocks without admitting any water. Two cases may be cited, not only to prove the safety of vessels fitted with the keels in question, but to show the strength of the fabric of ships built like the 'Medea:' those alluded to are the 'Lightning' and 'Flamer' steamers, constructed by Mr. Lang, and built under his superintendence. The former vessel, the 'Lightning,' on her first proceeding to sea, ran ashore a little below Sheerness, on the Spaniard shoal, and fell over on her side, where she lay dry at low water; she floated again at high water, and it was found she had sustained no damage. As she was entering Dover Harbour, soon after, she ran full speed against the pier and struck her fore-foot or gripe, knocking it over on one side, but made no water: on being docked at Portsmouth after this, her gripe was replaced, and no other injury appeared. The next important occurrence happened when at Jersey: being aground alongside the pier, and a rope made fast to her mast-head, secured to the shore, to keep her upright, the water having left her dry above 150 feet, the rope broke, and she fell violently down on her side: this shock was severely felt in the engine-room, but she sustained no injury in the hull or machinery by the fall; at high water she righted again, and sailed across the Channel to the Downs, where she was run into, just abaft the starboard paddle-box, by a loaded collier, which did the 'Lightning' but little harm in her topside and sponcing; but the collier, by the concussion, stove in her bows, ran on shore to save her from sinking, and became a wreck.

In the heavy gale of wind in February, 1833, the 'Lightning' was in the Irish Channel on her way to Dublin, with the 'Erin,' a large steam vessel, when the latter foundered in the gale, and the 'Lightning' had the misfortune to run on shore, but was got off with the loss of part of her keel and gripe; notwithstanding, she made the voyage in safety, continued at sea for two months after the accident, and did not leak in any part, was taken into dock, her keels and gripe replaced, and damages made good.

In the month of December following, the 'Lightning' sailed from Falmouth on the same day as her Majesty's steamer 'Columbia;' in the course of the day she passed her; the wind blew very hard, and increased to one of the most tempestuous gales that had been known for several seasons; so severe was the wind, that the 'Columbia' was obliged to put back, and from the situation in which she left the 'Lightning,' considered the latter had foundered; but the 'Lightning' proceeded on till she arrived at Corunna, and from thence to Lisbon. On her way to the latter place, when about 40 miles distant from it, she discovered a vessel in distress under the rock, firing guns, being on a lee-shore; the 'Lightning' immediately went to her assistance, and found her to be H. M. brig 'Plover,' of 10 guns, which had sailed from Falmouth eight days before the 'Lightning;' she towed her off from the land, and leaving her with a good offing, continued on for Lisbon, there

delivered her despatches to the Admiral, and returning to the 'Plover,' again took her in tow and conducted her safely into port.

In October, 1834, the 'Lightning' ran over the Coal Rock, near Elsinore, going between eight and nine knots; this had about a foot less water over it than her draught, but she was brought up against and hung by the middle upon another rock, where she remained ten hours, dropping and rising head and stern successively. The consequence was that her gripe, part of the fore-piece of the keel, and midship piece, by which she was hung on the rocks, were carried away, the whole of her keel all fore and aft about two or three inches from the under side against the rocks: after getting off in this injured state, she experienced a heavy gale of wind, which lasted four days, and from which she sought shelter at Heligoland; but there she parted both her cables, and was driven to sea: although the sea was running as high as her funnel, she shipped nothing but spray: at the same time the 'Superb,' a common-built steamer, was lost. It was observed by those on board the 'Lightning,' that while on the rocks and in the gale she did not work or strain in any part; not a seam or a butt opened, nor was even the pitch broken in any place; no sign whatever of altering her form but remained perfectly tight. On repairing the keel, it was found, on removing the damaged part, that it was quite dry within, and no water had penetrated into the hull of the vessel; the caulking of the seams and wood ends, notwithstanding the heavy shock in dislodging the gripe and keel, was hard and sound, and not started in the least, thus proving the strength of the fabric; since which she has been on shore on the coast of Spain, while employed on that service in January, 1837, rubbed off the copper from her keel, and in February, 1838, at Holyhead, she had the misfortune to run on the rocks, and struck off her gripe and foremost piece of keel, immediately after which she encountered a very severe gale of wind for three days, and did not strain or leak in the smallest degree. This vessel has also performed many difficult voyages to various parts of the world, viz. the Mediterranean, Spain, Portugal, France, Holland, Denmark, Sweden, Russia, Scotland, Ireland, &c., and experienced very bad weather. She was at the battle of Algiers, and was very useful in towing and placing the ships in order of battle, and towing from under the batteries such vessels as drifted within the reach of the enemy's guns.

The 'Flamer' went on shore on the rocks at Zante in the Mediterranean, going nine knots, and ran up two feet less than her draught of water; she remained on shore twenty-two hours, carried away her fore-piece of keel and gripe, tore off the copper from her bilge, and injured the plank of her bottom; she was lightened, got off, and came to England safely: previously she was run into by a Spanish ship just abaft the paddle-box, which stove in the sponcing at that place without affecting the 'Flamer' in any other part: the Spaniard received much damage in running foul, and on getting clear, left the knee of her head behind, which was broken off in the 'Flamer,' and brought home. When taken into dock about six weeks after, the caulking was found hard and sound, even close to those parts of the keel that were carried away, and the ship showed no appearance of straining, or having suffered in her fabric by the violence of the blows she sustained in running on shore or by being struck by the Spaniard. On this principle of strength, Mr. Lang commenced the construction of sea-going steamers, having designed and built the first for sea service, an experiment at that time considered impracticable.

The steam vessels he has constructed for Her Majesty's Service are, the 'Comet,' 237 tons, engines 80 horse-power, for towing men-of-war from one port to another; 'Advice' (late 'Vixen'), 185 tons, engines 80 horse-power, for the Post-Office service between Holyhead and Dublin; 'Lightning' and 'Meteor,' 296 tons each, engines 100 horse-power, for towing ships and any sea service required; 'Pluto,' 365 tons, 100 horse-power, for the suppression of the pirates on the Bahama Banks, armed with two long eighteen-pounder guns, one afore and one abaft, on a carriage and slide to

traverse on a sweep; 'Flamer,' 492 tons, 120 horse-power, and 'Firebrand,' 492 tons, engines 120 horse-power, Mediterranean packets; (the 'Firebrand' afterwards became the Admiralty yacht;) 'Medea,' 843 tons, engines 220 horse-power, war steamer; 'Firefly,' 549 tons, engines 140 horse-power, and 'Spitfire,' 553 tons, engines 140 horse-power, Mediterranean packets; and 'Ionia,' 263 tons, engines 90 horse-power, packet for the Ionian Islands; all which are built on the same mode of security as the 'Medea,' and have proved to be excellent sea boats, possessing speed, ease, and comfort, combined with superior strength of fabric.

The PLATE marked 4 should be placed to follow Plate XXXI.

(See page 21, and the List of Plates.)

HERNE BAY STEAM PACKET 'RED ROVER.'

The engines, two of 60 horse-power, were by Messrs. Boulton and Watt, and the vessel was built by Messrs. Fletcher, Son, and Fearnall, London; launched 28th March, 1835, for the Herne Bay Steam Packet Company.

PRINCIPAL DIMENSIONS OF THE HULL.

	ft.	in.
Length between the perpendiculars	154	0
Breadth to the outside of the bottom plank	22	4
Depth at shaft from top of floor timber to the under side of deck	10	4
Burthen in tons, $376\frac{3}{4}$ (builders' measurement).		

This vessel was constructed for the conveyance of passengers and luggage to and from London to Herne Bay with the greatest possible despatch, and comparing her displacement and power with other similar vessels, was then the fastest running out of the Thames. This superiority of speed was chiefly effected by a novel mode of building, a mode combining the fourfold advantages of increased buoyancy, a more uniform diffusion of strength, prevention of rot by exclusion of surfaces, and affording the greatest possible facility to repairing.

The bottom, or that part of it on which the engines and boiler were fixed, was composed of stout floor timbers going from bilge to bilge, placed close together and dowed and bolted to each other, and planked externally with the best well-seasoned four-inch Dantzic deals, fastened in the usual manner; but above, before, and abaft this part of the bottom so wrought, the timbers of the frame used in common were omitted, and the plank continued of the same thickness to the top of the sides, having the edges grooved and tongued, and secured to each other by $\frac{3}{4}$ -bolts driven through the edges in a diagonal direction at about 15 inches apart; in addition to which, long diagonal iron plates, 4 inches broad by $\frac{5}{8}$ ths of an inch thick, placed at an angle of 65° , and 2 feet 6 inches from each other, were worked each on a Dantzic fir plank $2\frac{1}{2}$ inches thick and 9 inches broad, the whole secured by a through-bolt in each outside strake, having a screw point and nut setting up on the diagonal plate inside the vessel.

It must be obvious to all persons acquainted with the nature of ship-building, that the hull of a vessel so built would offer the greatest advantages to the caulking, requiring but half the usual quantity of oakum, and that stopped from being driven through the seams by a strong oak tongue bedded in white-lead uniting the edges of the planks. The uniform strength of the entire hull exceeded all expectation.

ROTATORY ENGINE, PATENTED BY JOHN BEALE, ESQ., C. E., EAST GREENWICH.

The peculiar character of this engine is fully illustrated in the engraving.

Fig. 1 is a view with the near end plate removed, and the cylinder in section. In a cylinder A an eccentric drum B revolves, carrying round with it the compound slide C, the heads of the slide being kept against the cylinder by the aid of the pieces D D, which, being pierced for that purpose, take hold of the pins *a a* upon the slide-heads, and being confined in circular grooves E in the end plates, carry the heads of the slide concentrically with the cylinder: to allow for wear or any inaccuracy, the heads of the slides are furnished with metallic packing.

The periphery of the drum is not in contact with that of the cylinder, the steam-tightness of that part being secured by the dovetail slips, which do not require springs, as it is found in practice that the steam which enters the dovetail recesses after the slips have been depressed by contact with the cylinder is sufficient to insure their action as perfect steam stops.

Figs. 2 and 3 are a section and elevation, showing the construction of the end plates; they are double, the inner one being made of such a thickness that whilst having sufficient stiffness, it possesses a certain amount of flexibility: it has firmly tapped into it several studs *a a a*, which, passing through stuffing-boxes on the outer end plate, are mounted with jam-nuts. Whenever it may be deemed necessary to adjust these ends, the jam-nuts are loosened, and the engine led round, with the steam on, the flexible ends are forced by the steam into contact with the drum and slide, and the engine being stopped successively at those portions of the revolution where the slide passes directly under the studs, a smart blow is given to the top of each stud, and the jam-nuts are cautiously tightened, their use being to allow of adjustment and to prevent the flexible ends from being forced harshly against the drum and slide by the steam in the jacket between the two end plates.

A mode of packing the pieces D D, and various other details here omitted, are given in the specification of the patent.

In the Plate the engine is represented as working expansively, the steam flowing through the steam-pipe *c* into the slide-box *d*, and into the passage *e*, from whence it flows right and left into the recesses formed between the two double end plates: the inner or flexible end plates have ports through which (when the flying ports *f f* in the drum pass over them) the steam flows into the cylinder and drives the slide or piston forward until it has passed the port *g*, when the steam escapes into the exhaust port *h*. To work the engine at full pressure, the slide is elevated till the port *i* is opened; to reverse, the slide is depressed to the end of the slide-box, so as to make the port *g* the inlet and the port *i* the outlet.

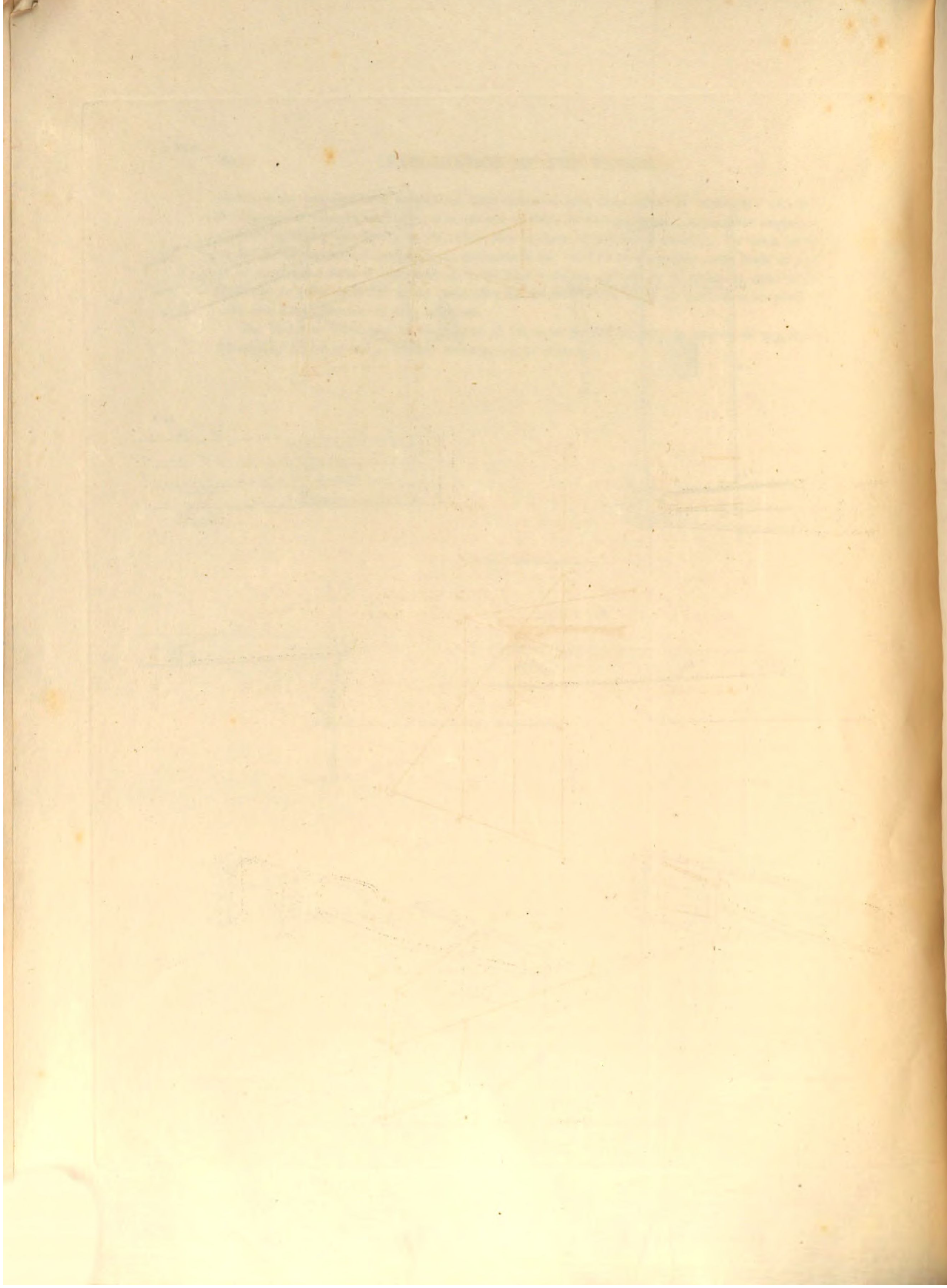
Fig. 4 is a section of an air-pump, which is so analogous to those in ordinary use as to require no description: the smaller diagrams exhibit various proportions and modifications of these engines and pumps, according to the purposes to which they are to be applied,—as gas-exhausters, &c. &c.

These engines run at high velocities with almost perfect freedom from noise or vibration; they are very compact in comparison with other engines, and extremely easy of management, as they are capable of being stopped or reversed instantaneously. From the uniformity of power, one engine suffices, which gains great economy of cost: they are readily applicable to stern-propellers, going

direct to the propeller-shaft without the intervention of gear lying below the water-line; and from the absence of external machinery, they are not so liable to damage or accident as other engines.

The remaining two figures on the Plate show a form of propeller included in the same patent as the above engines and pumps: it is denominated the 'bird's-wing propeller:' each blade or wing is so constructed that, if continued, it would form a hollow cylinder at or nearly at right angles with the propeller-shaft, but at the same time so fashioned as to be of an uniform mean pitch at each and every diameter, or very nearly so.

The blades or wings may be constructed of the outer portion or skin, as it were, of any figure bounded by circles around a common centre or line of centres.



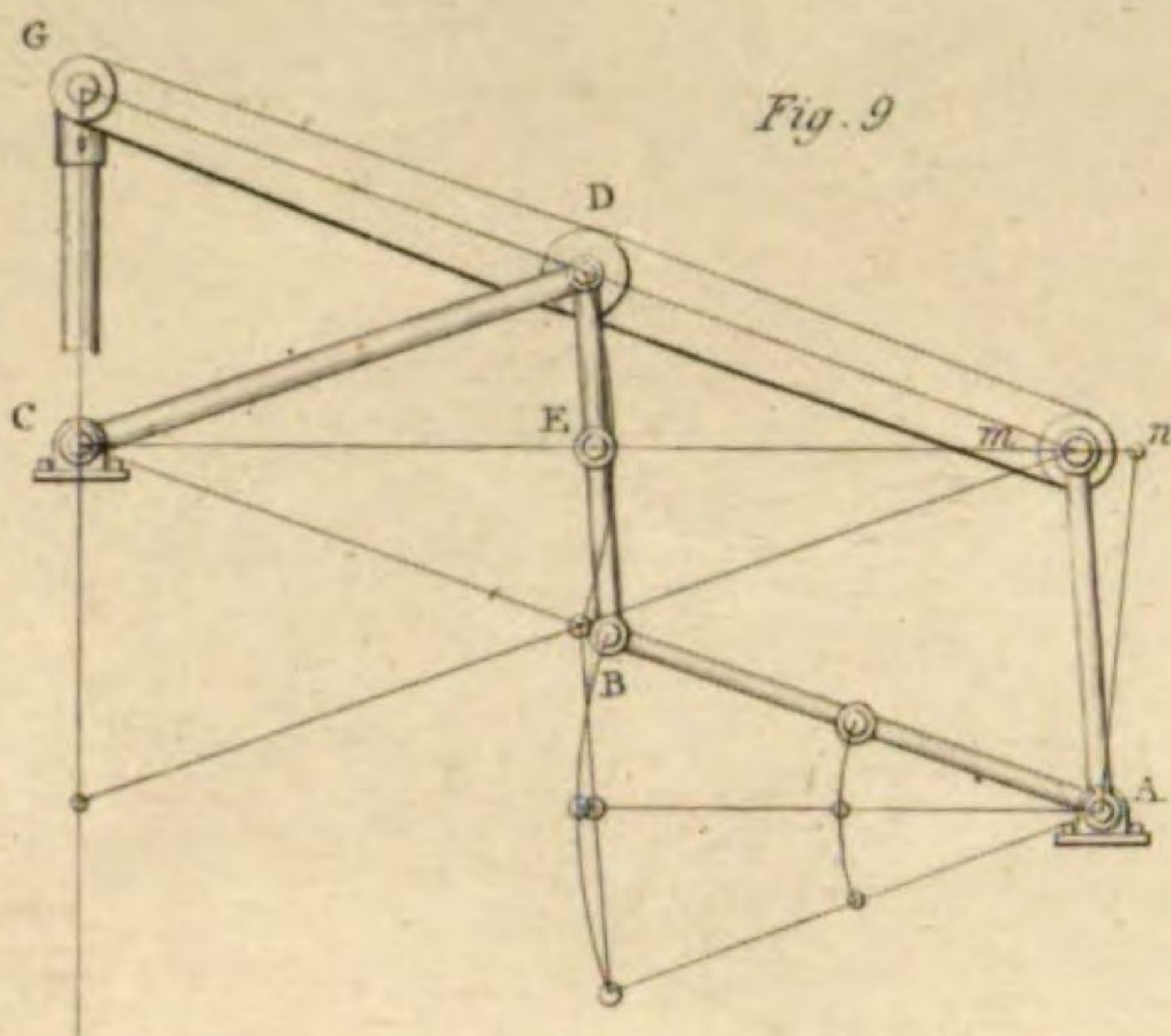


Fig. 9

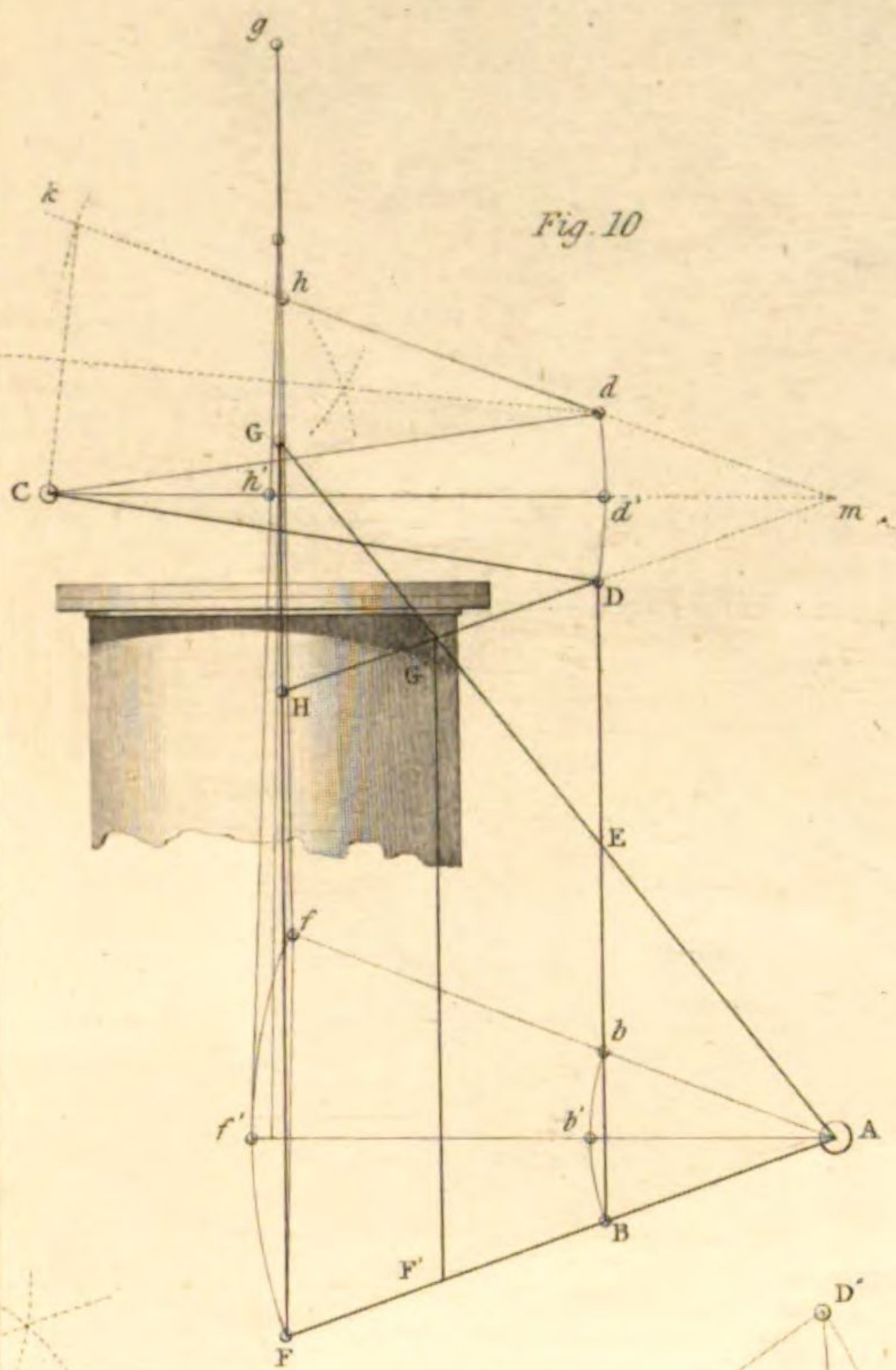


Fig. 10

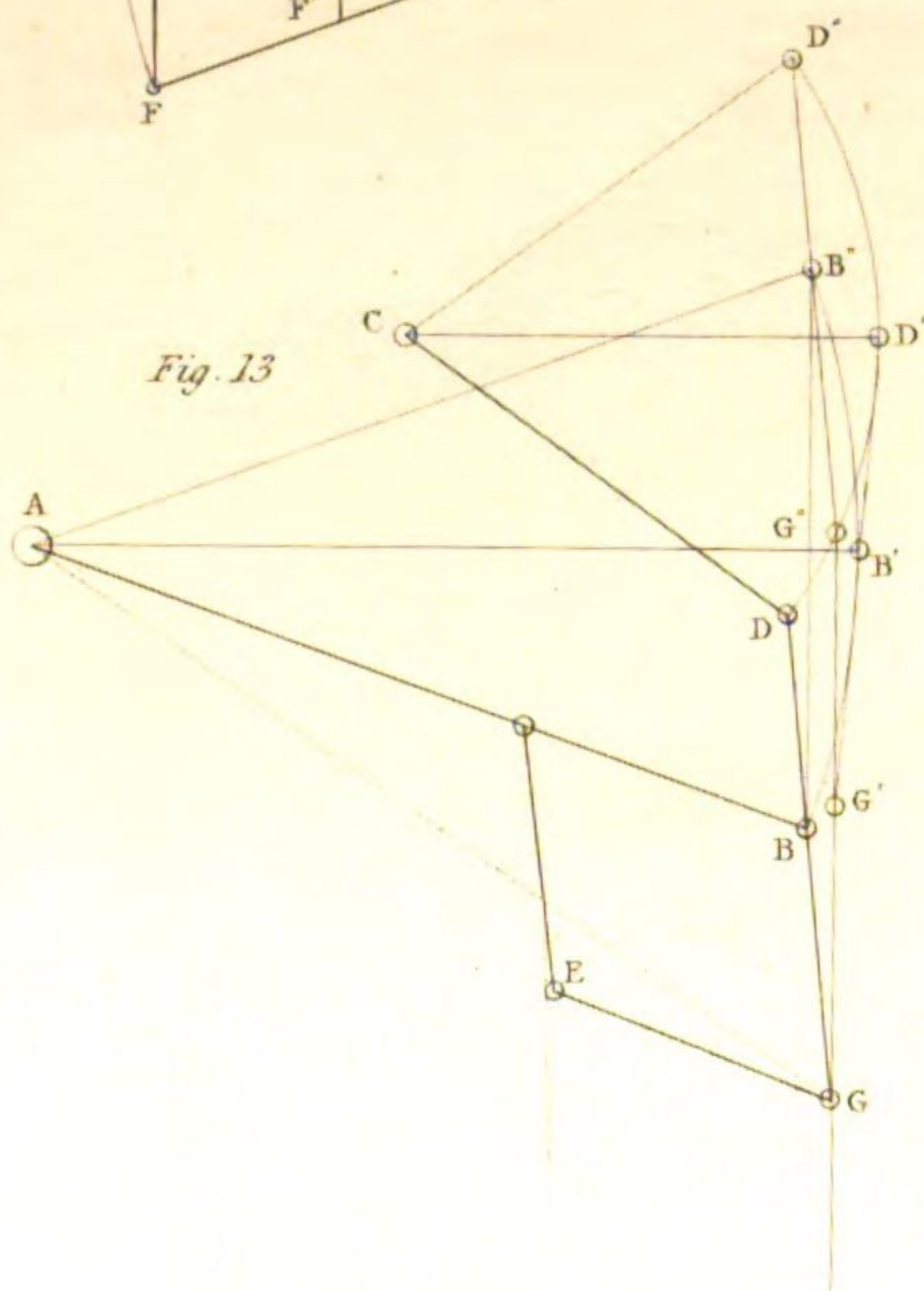


Fig. 13

Fig. 1.

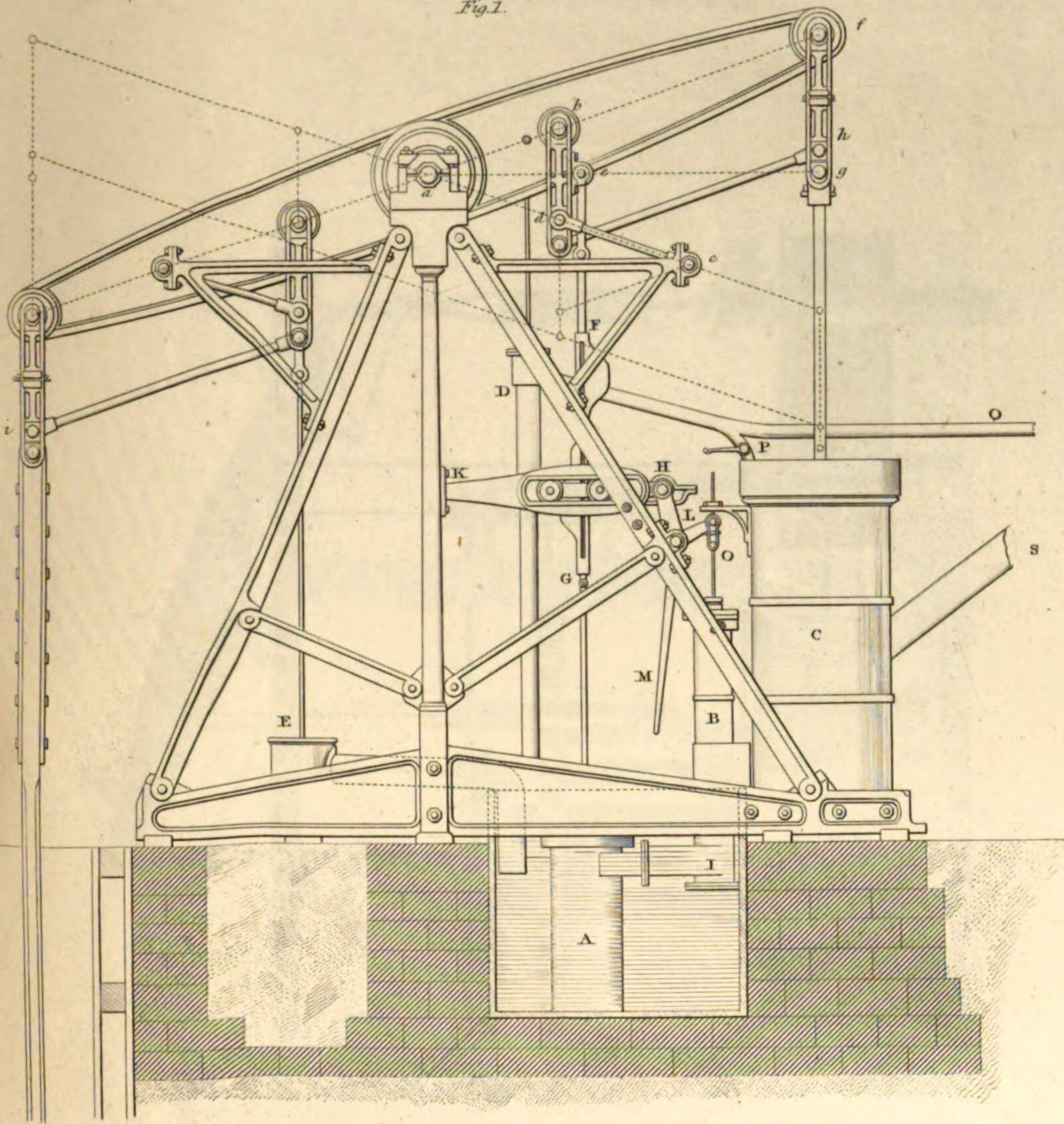
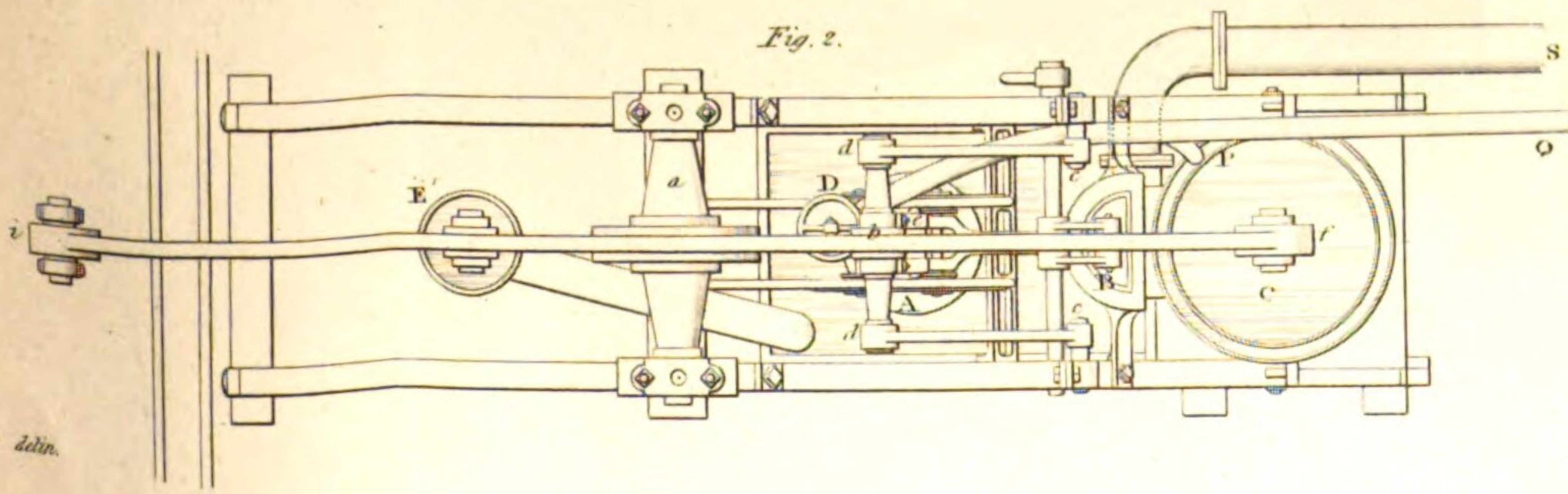


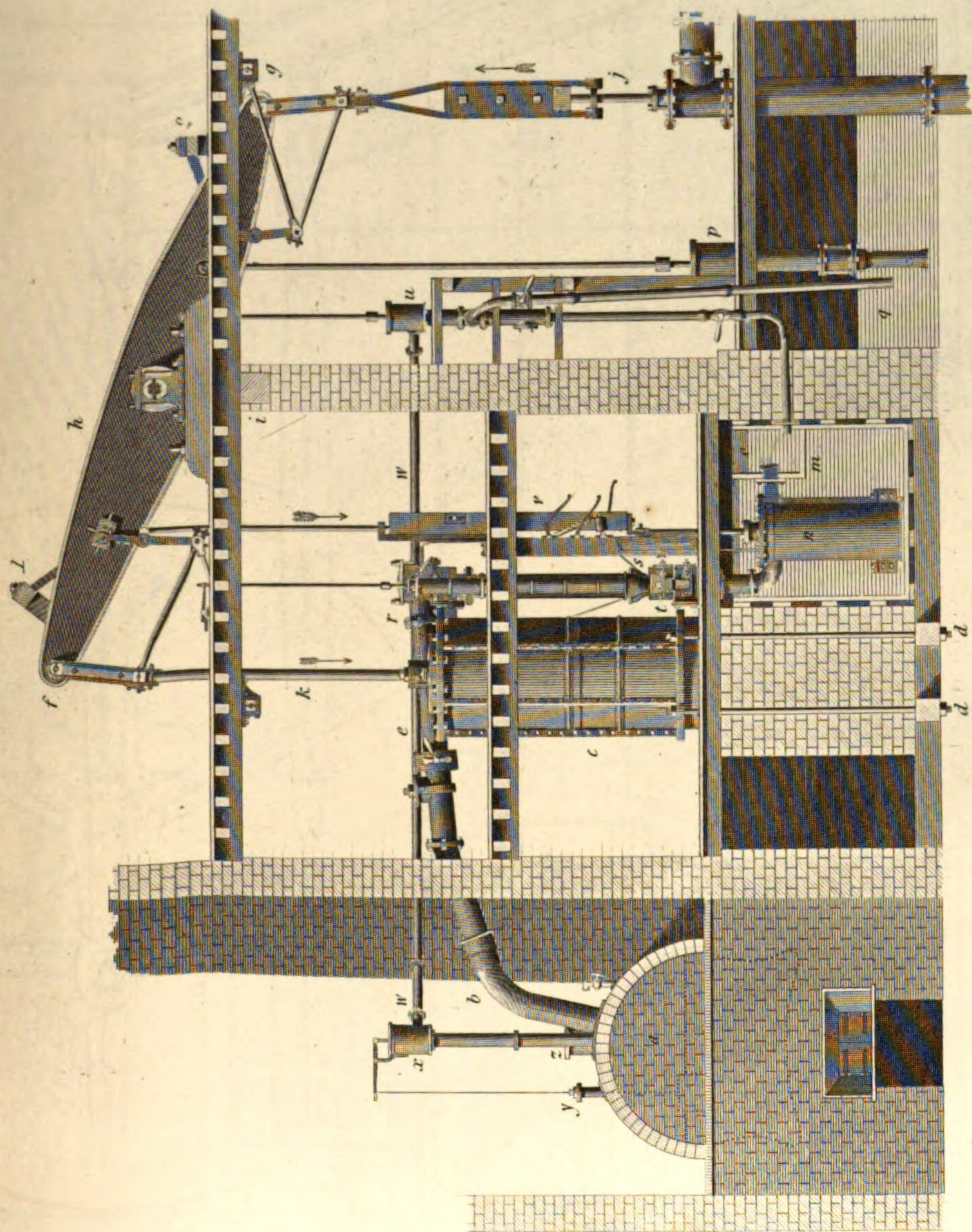
Fig. 2.



L. Redgold delin.

G. Gladwin sculpt.

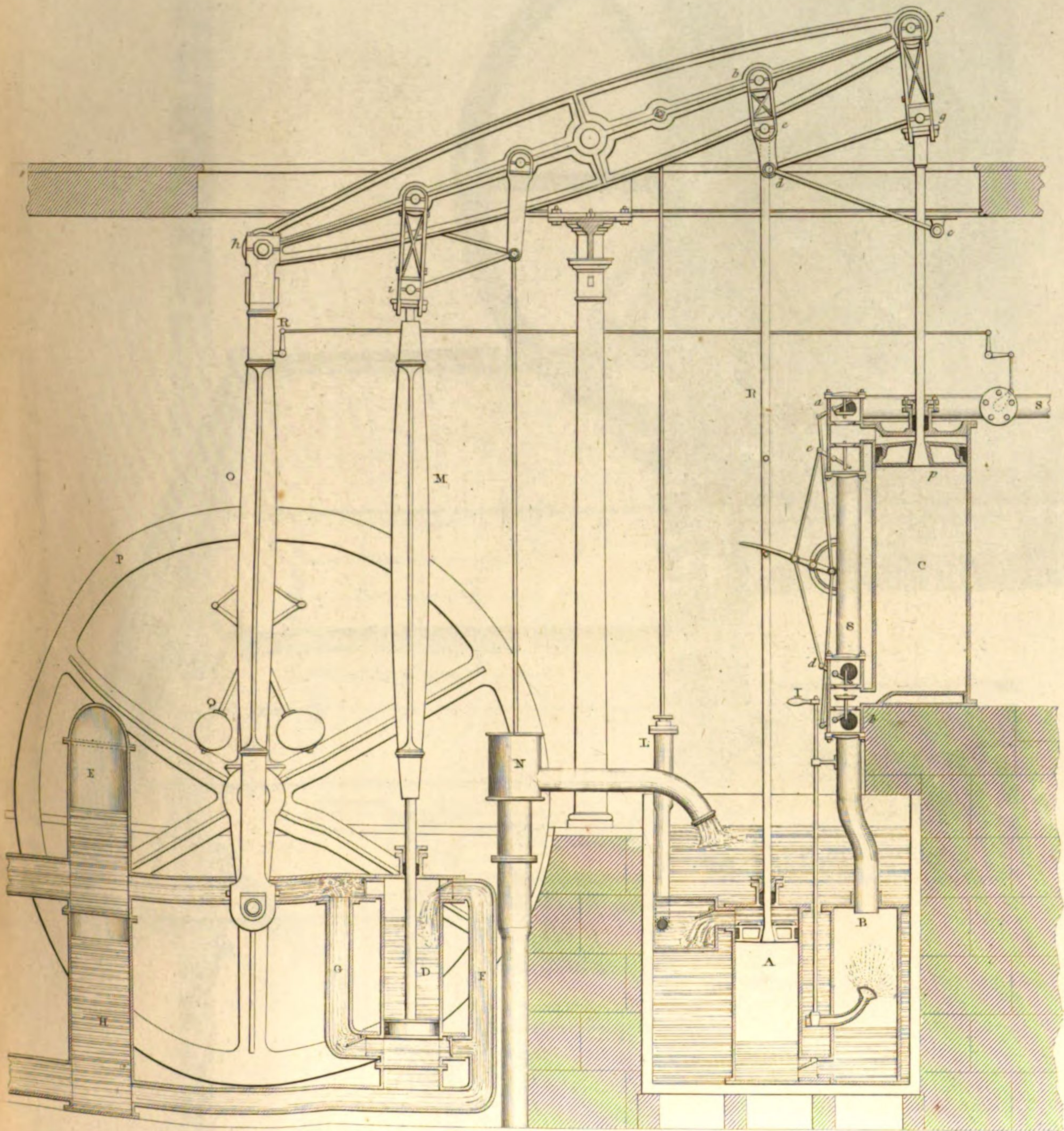
Single Acting Engine by Boulton and Watt.



Drawn by J. Clement.

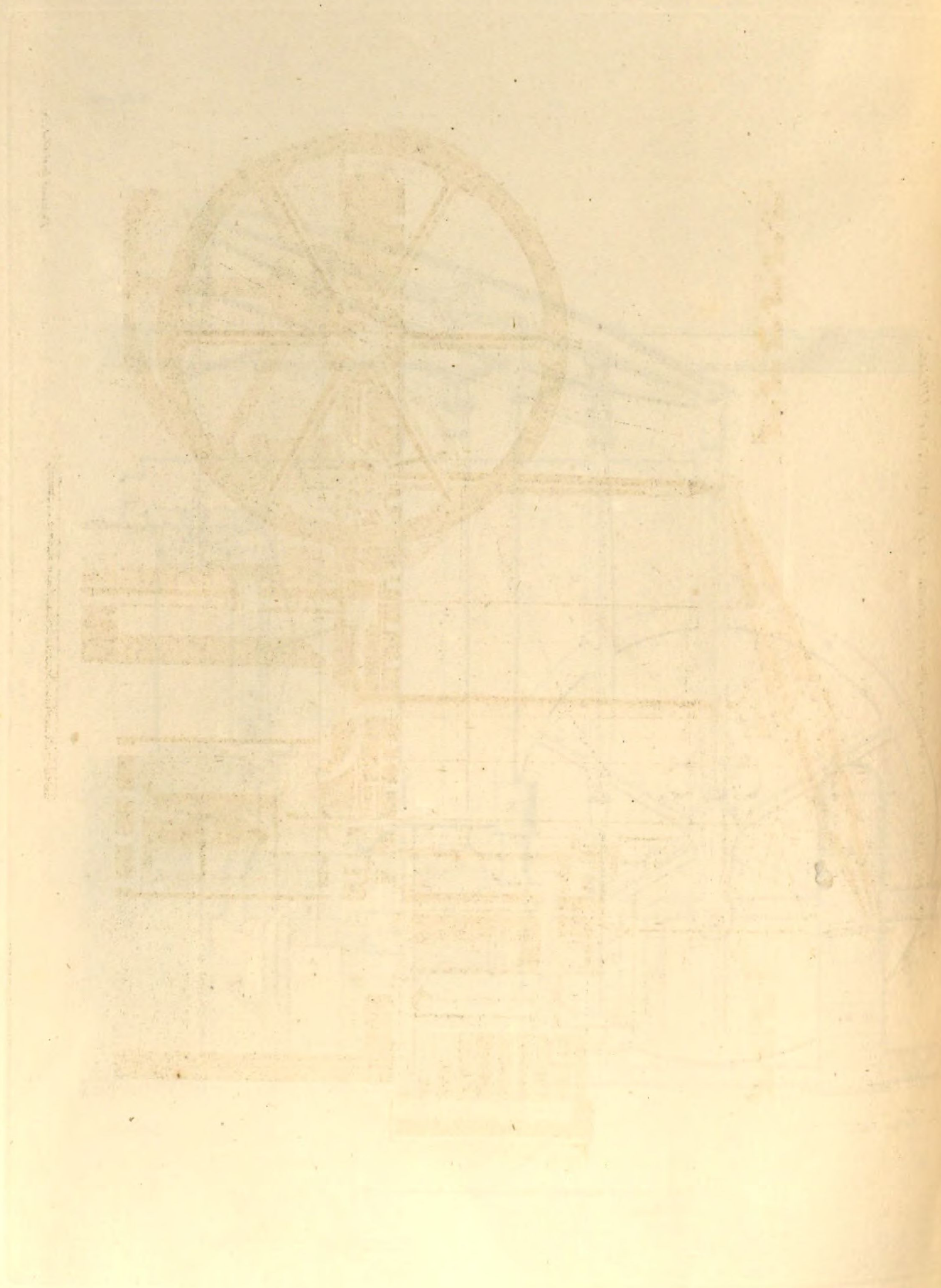
Engraved by C. Gladwin.

London, Published by J. Weale, at the Architectural Library, 38, High Holborn, 1852.



J. White delin.

G. Glavin sculp.

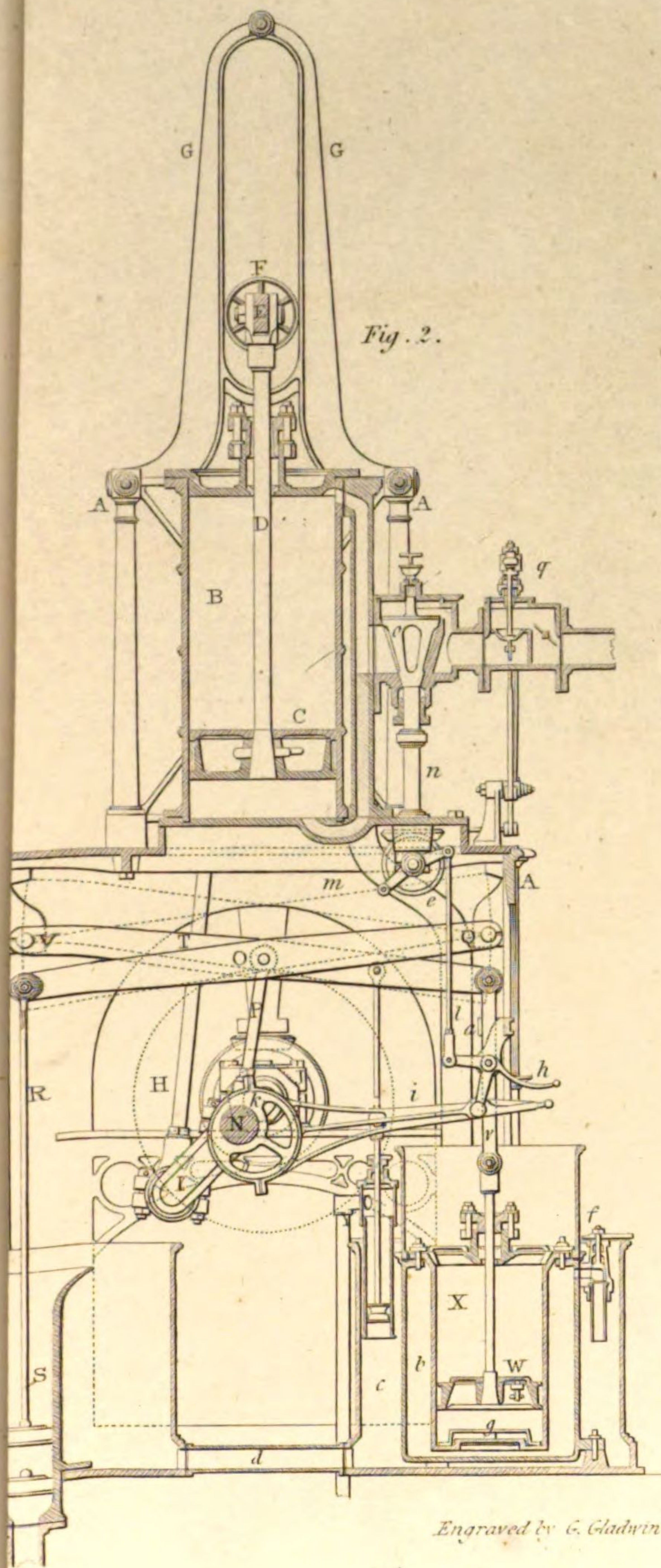


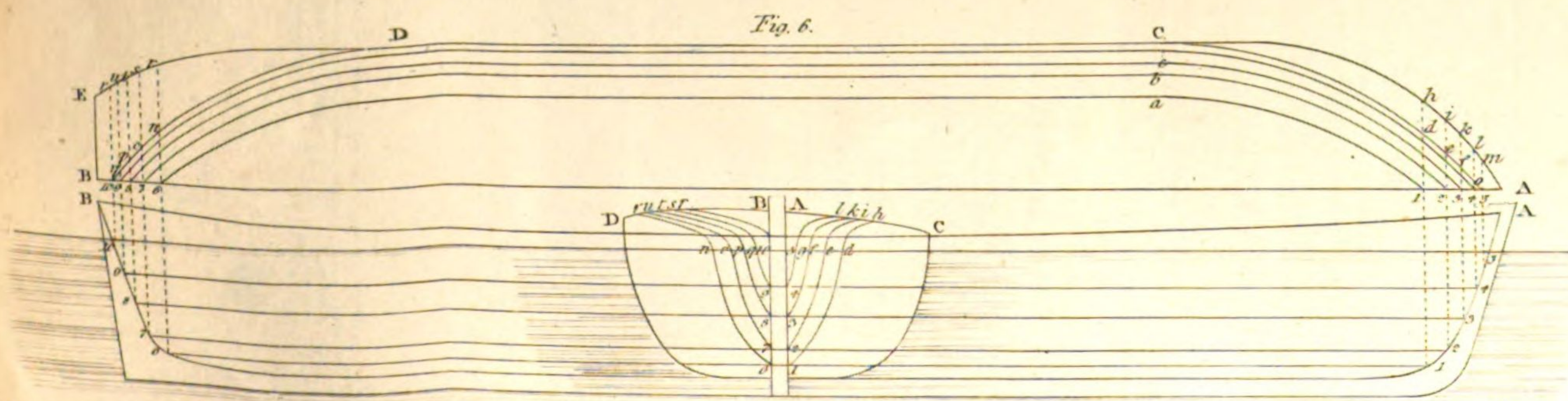
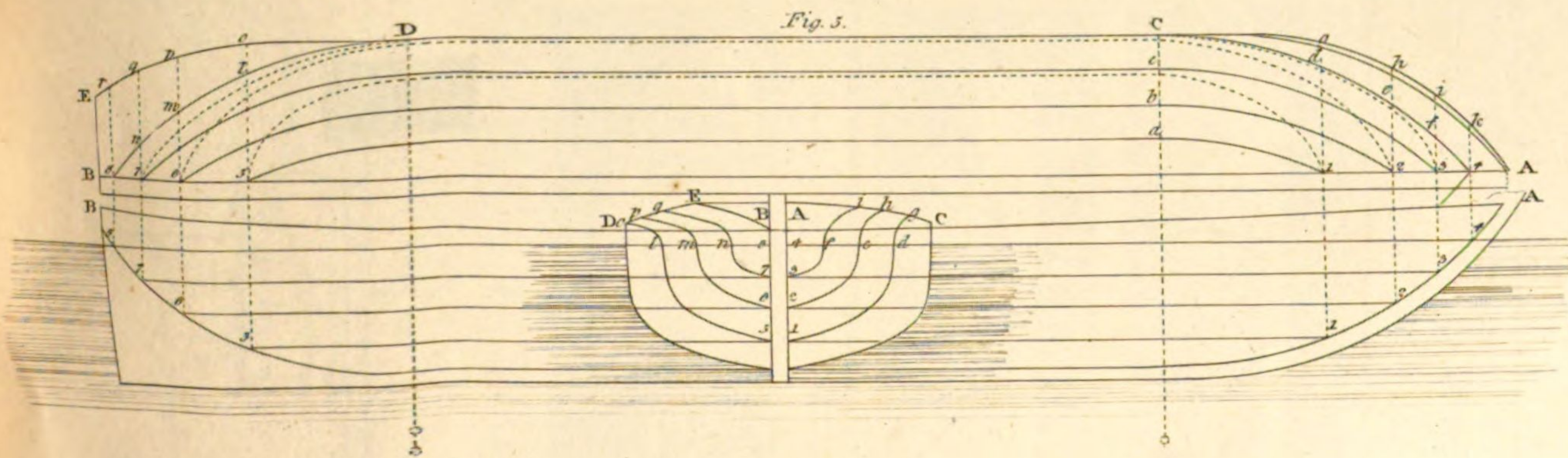
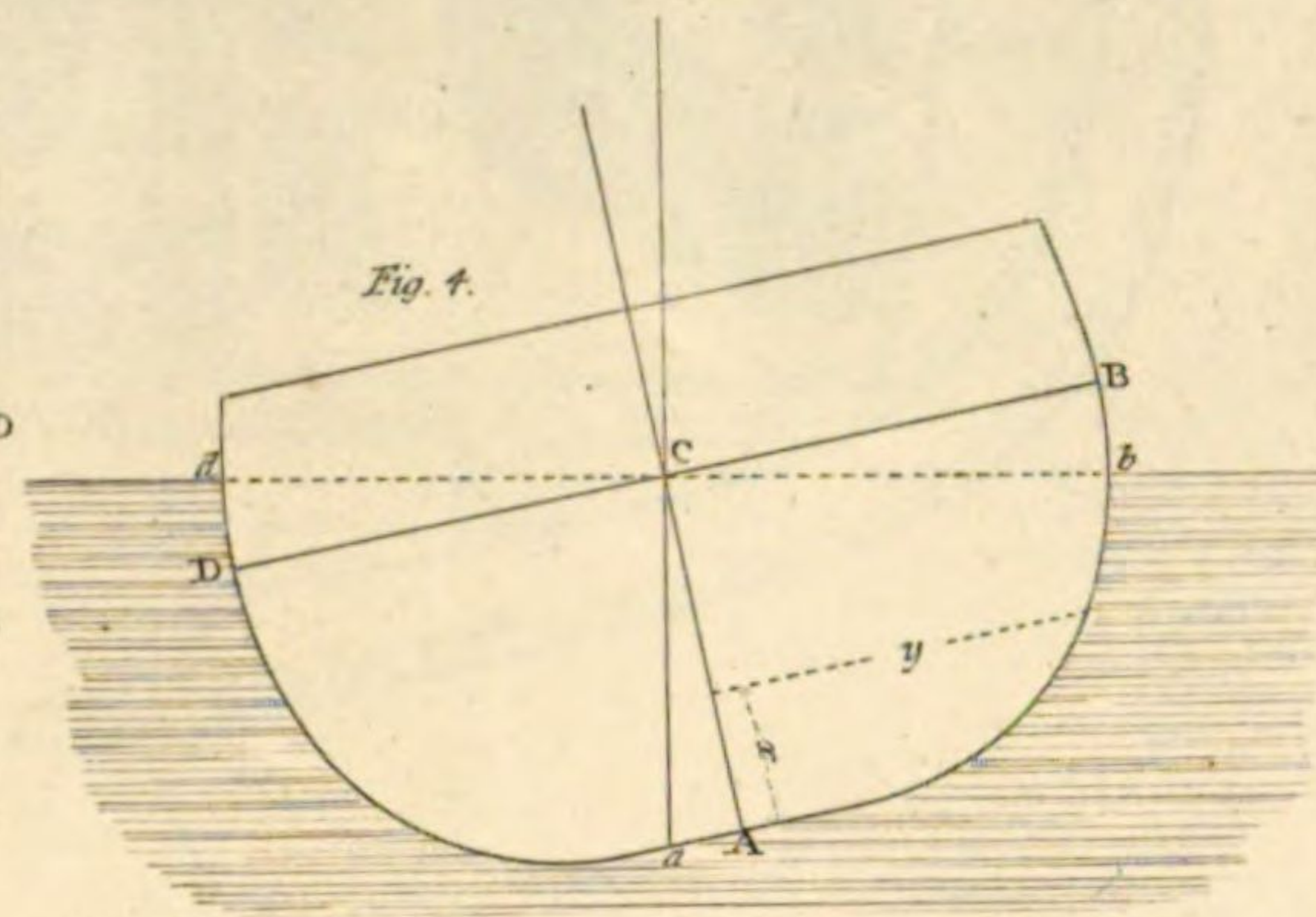
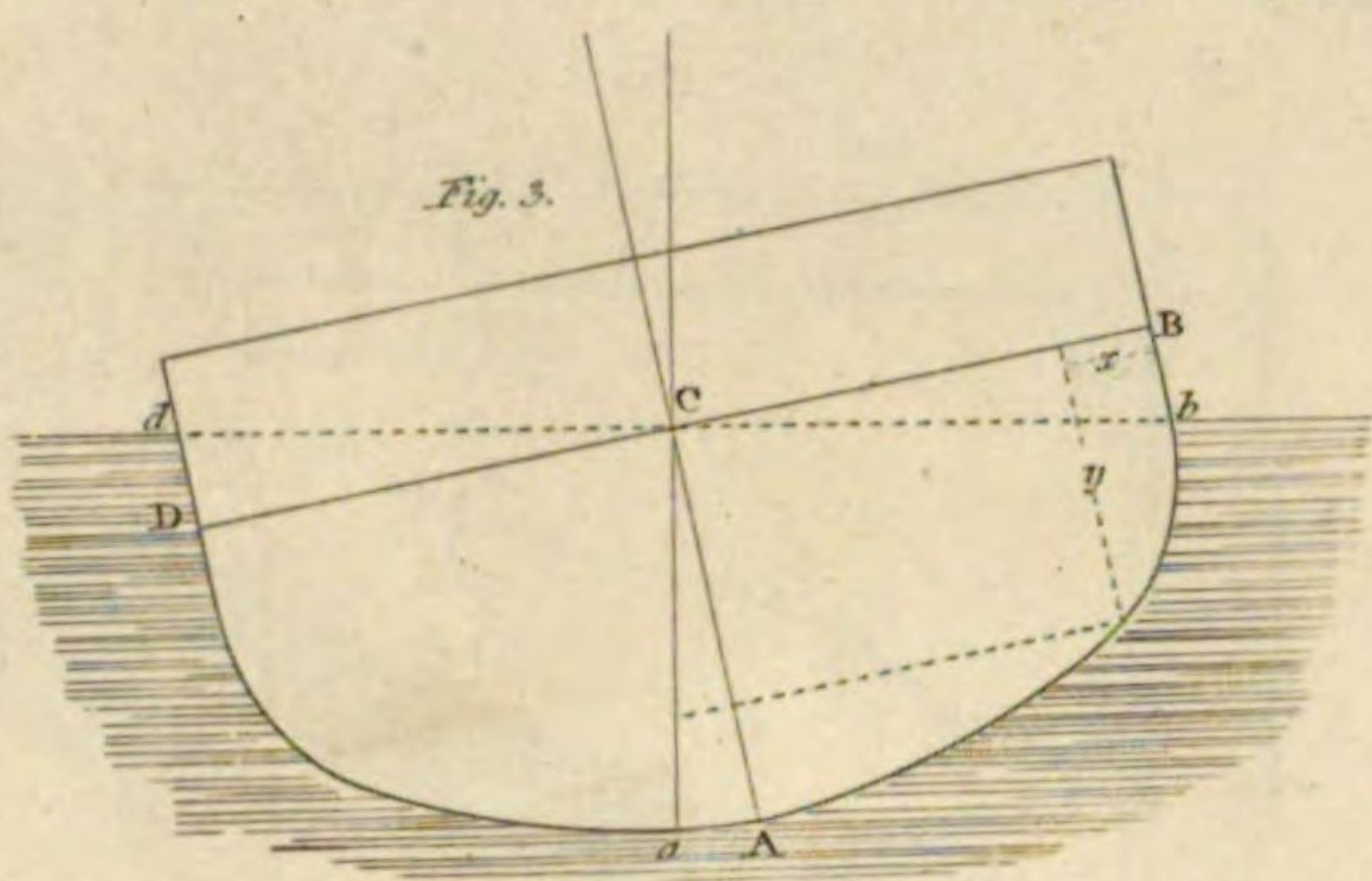
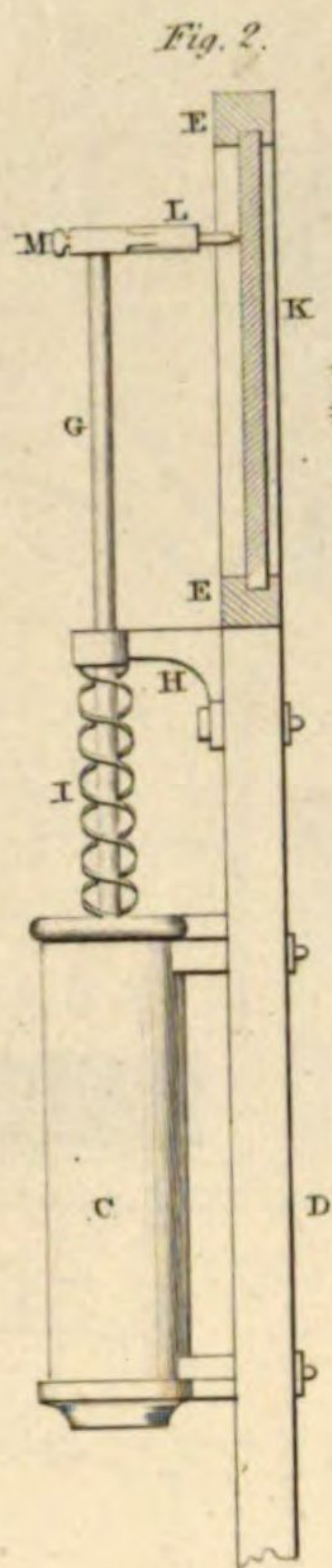
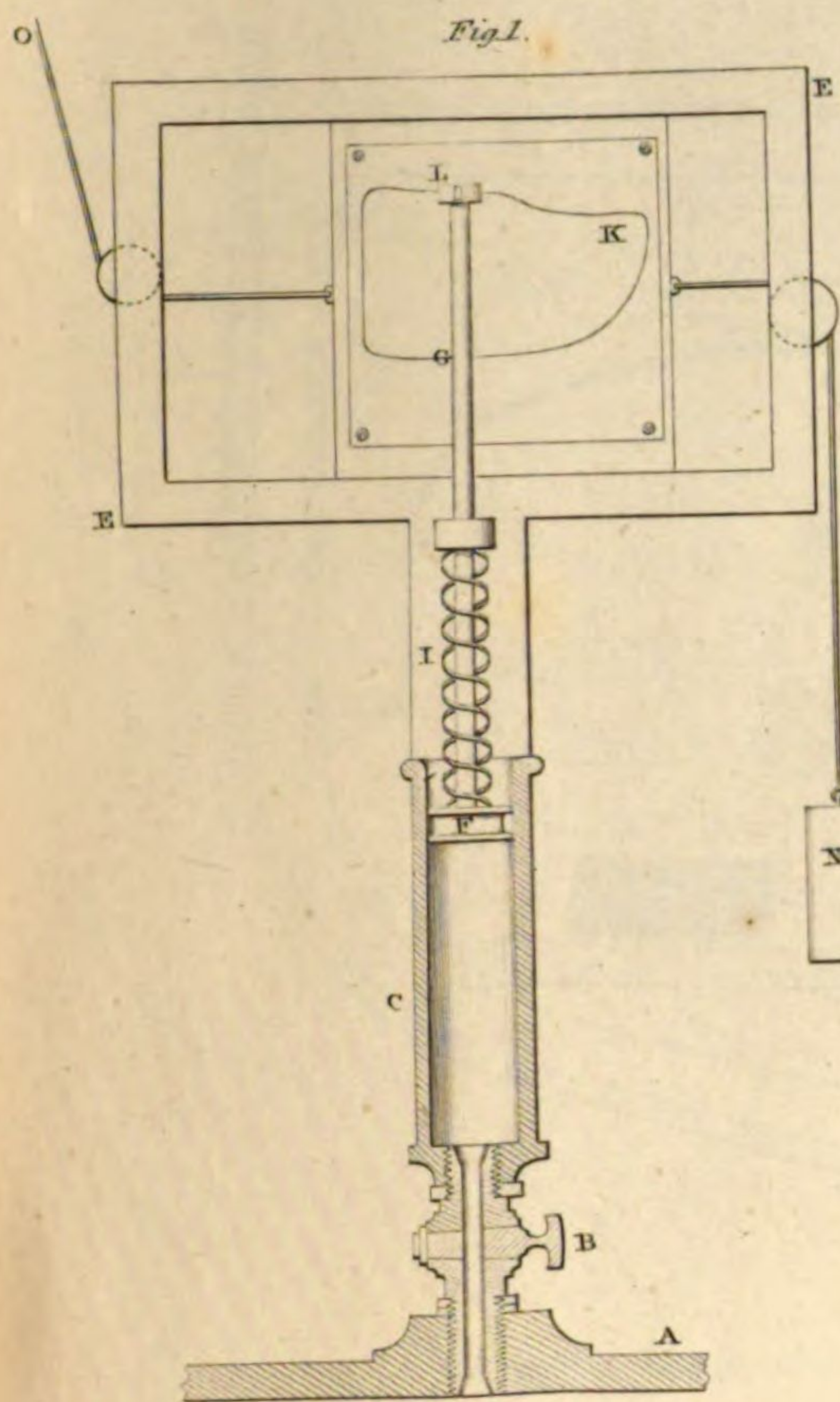


Engraved by G. Gladwin.

London. Published by J. Weale, at the Architectural Library, 59 High Holborn, 1881.

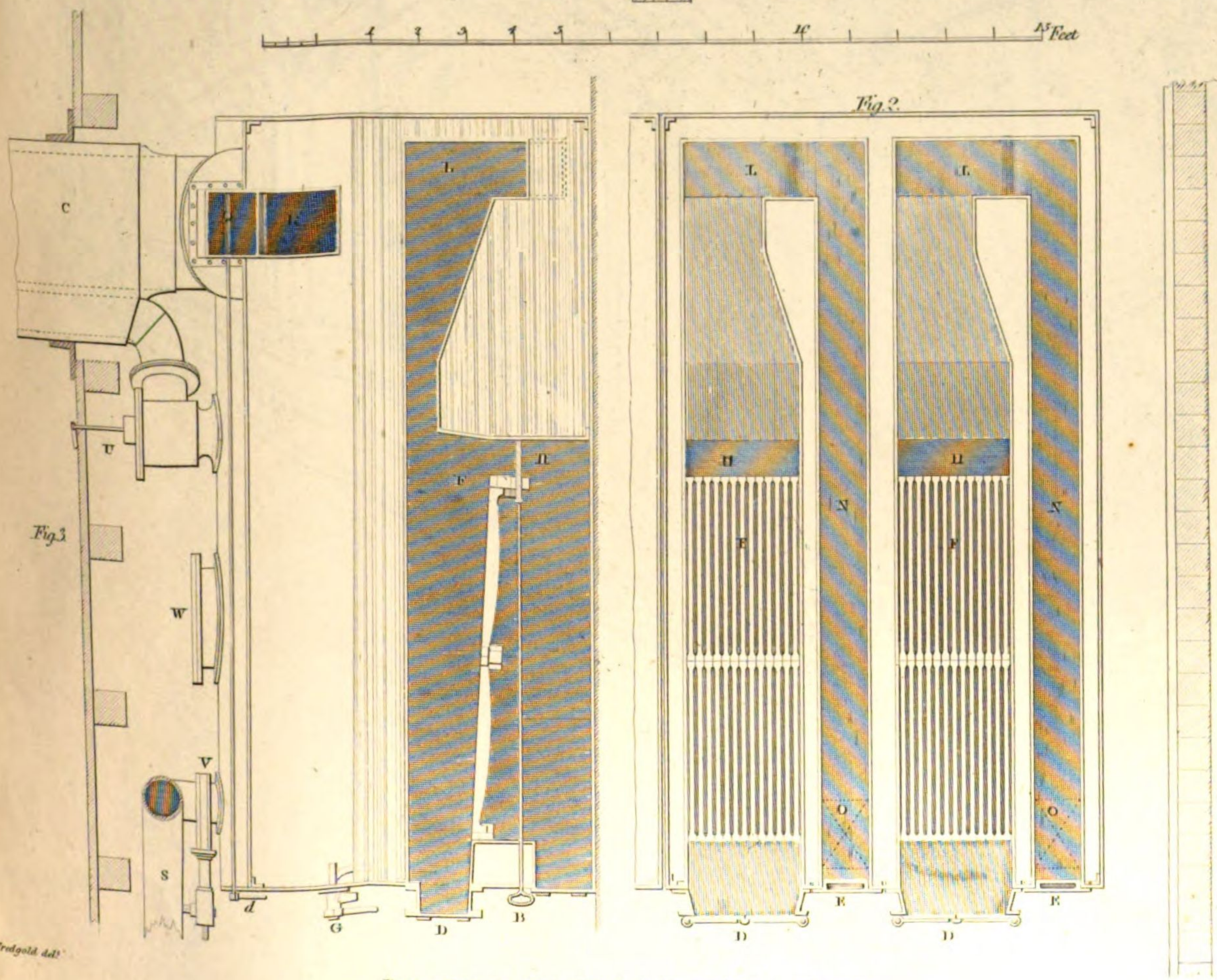
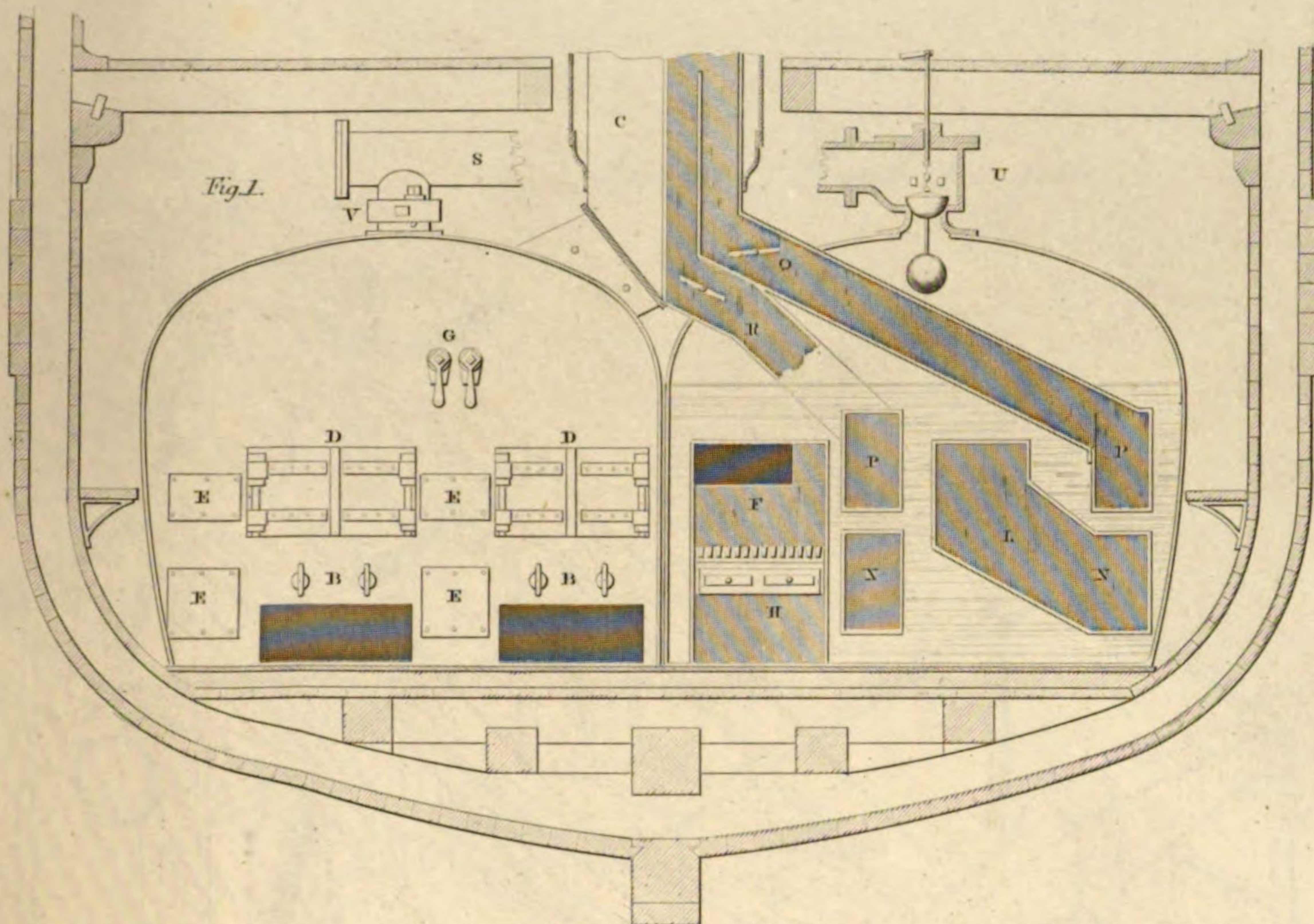




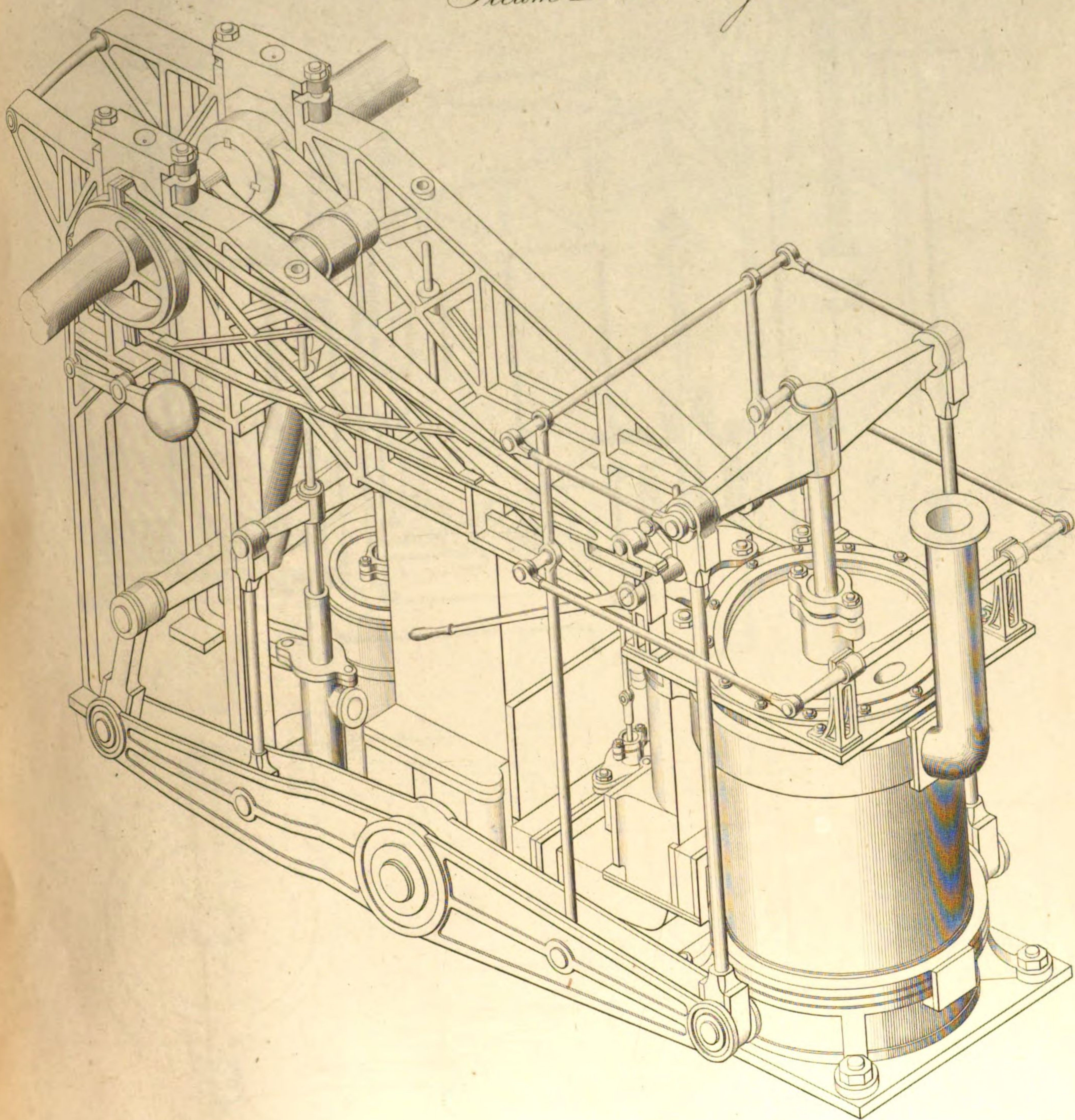


T. Tredgold delin.

G. Gladwin sculp.



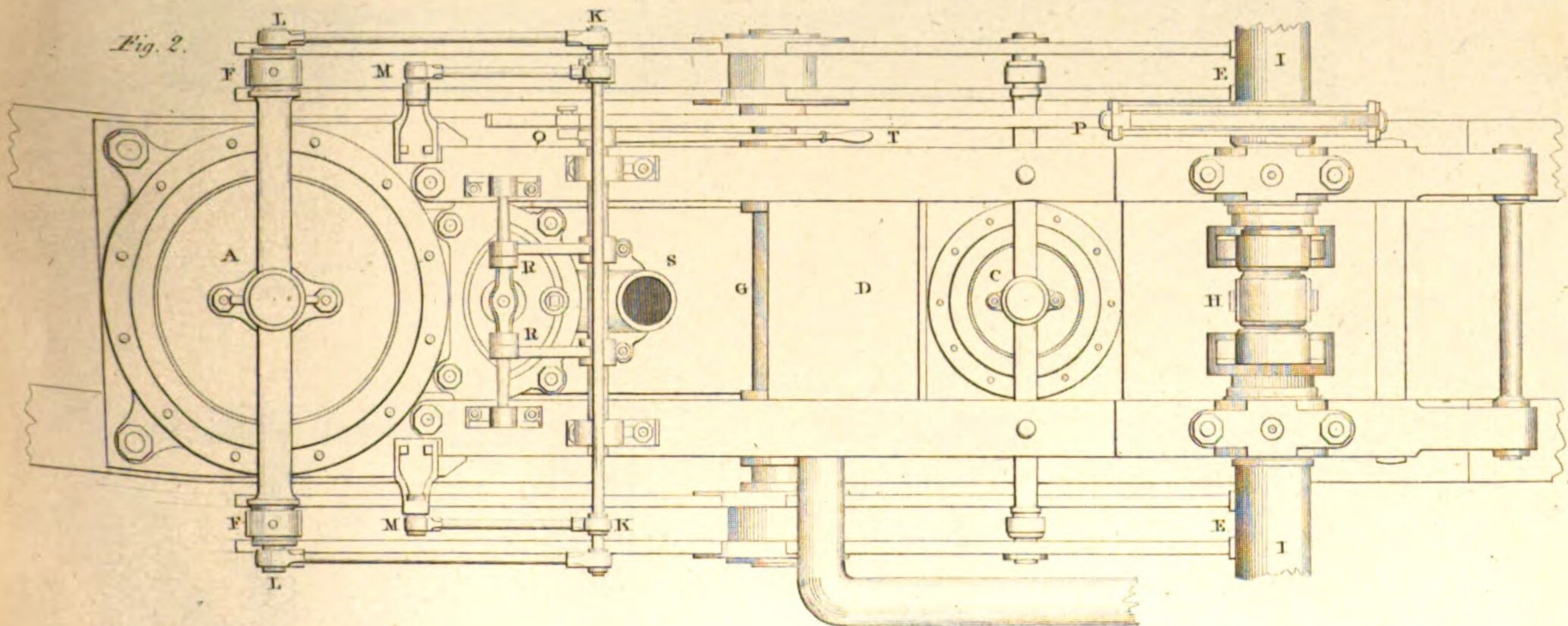
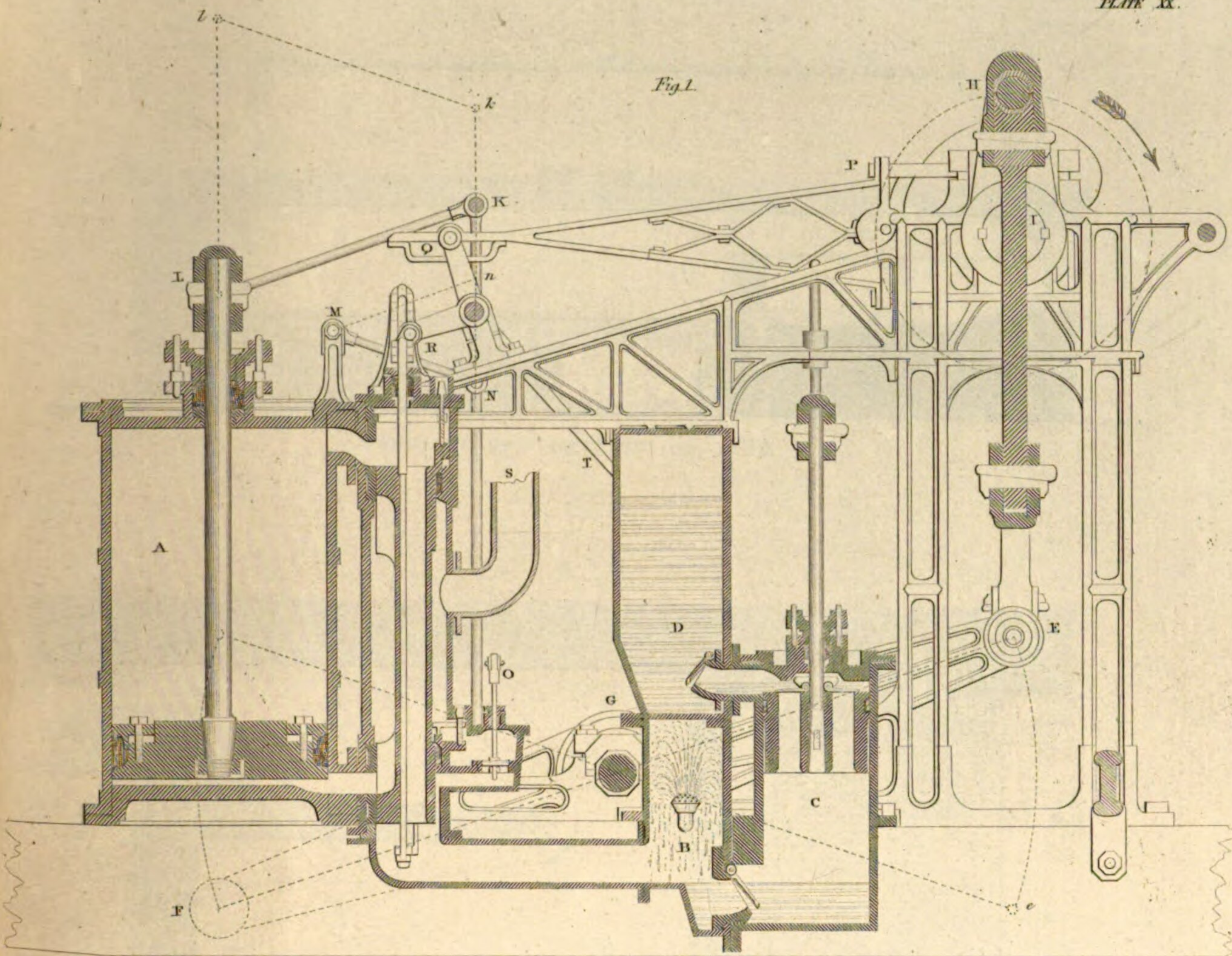
Steam Boat Engine.



T. Tredgold delin.

G. Blair sculp.

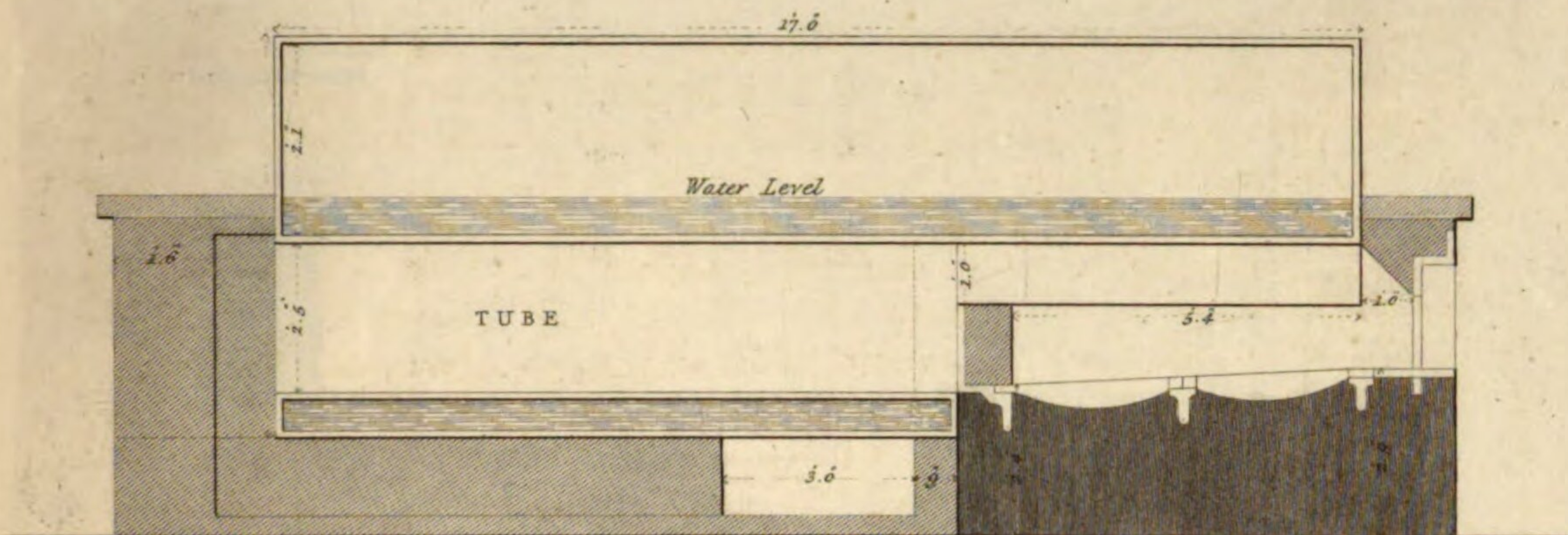
London, Published by J. Weale, Architectural Library, High Holborn, 1851.



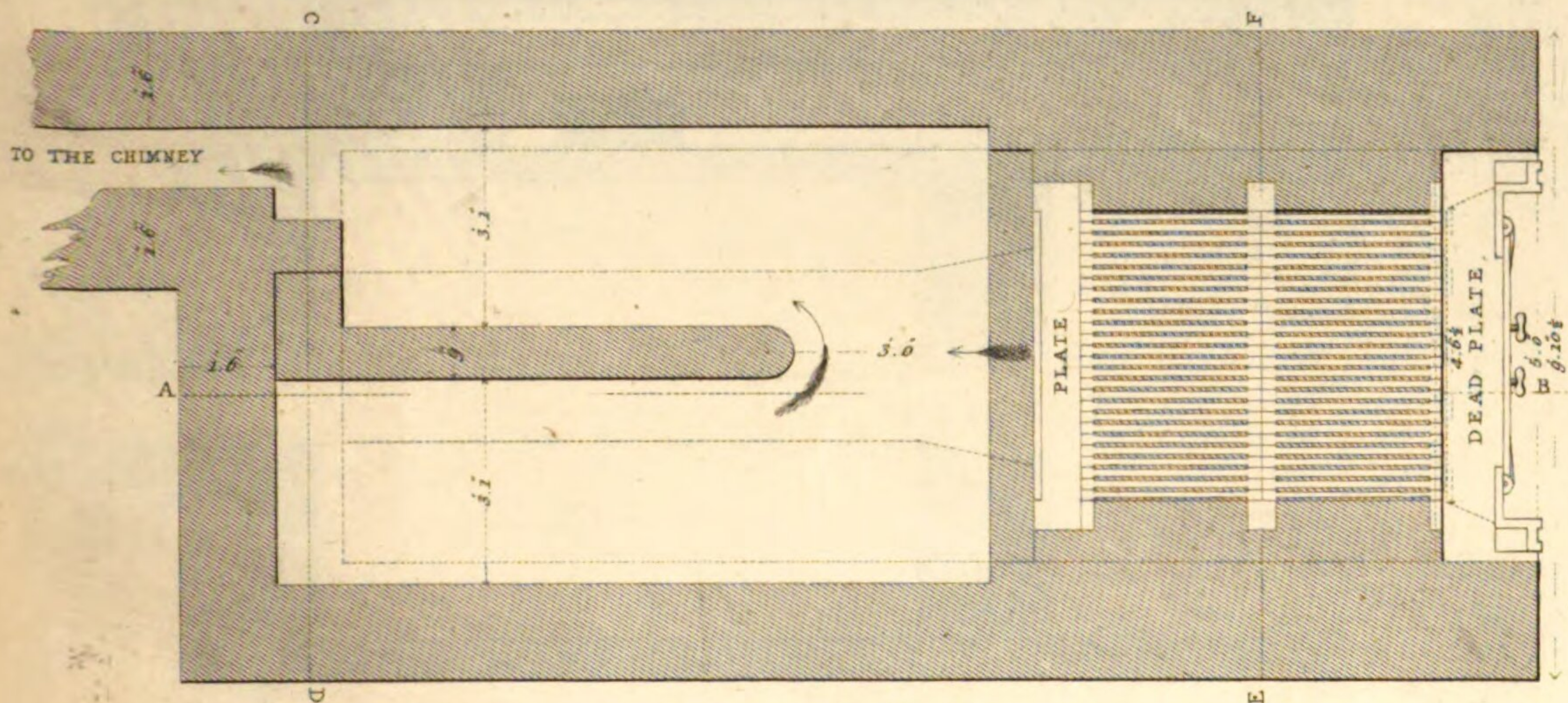
T. Tredgold delin.

G. Gladwin sculp.

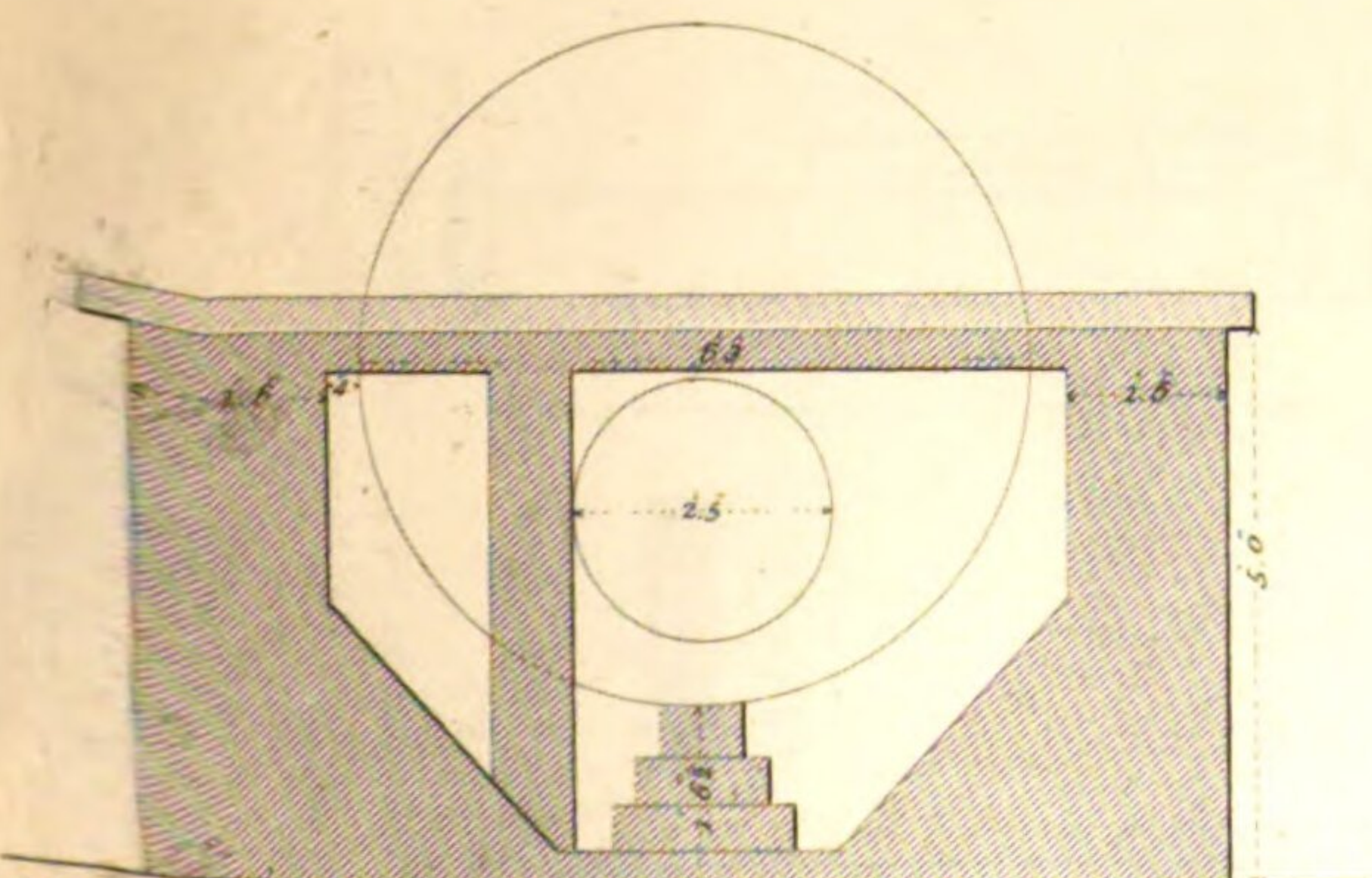
HORSE
PLAN AND SECTIONS OF BOILER SEATING FOR A TWENTY ENGINE.



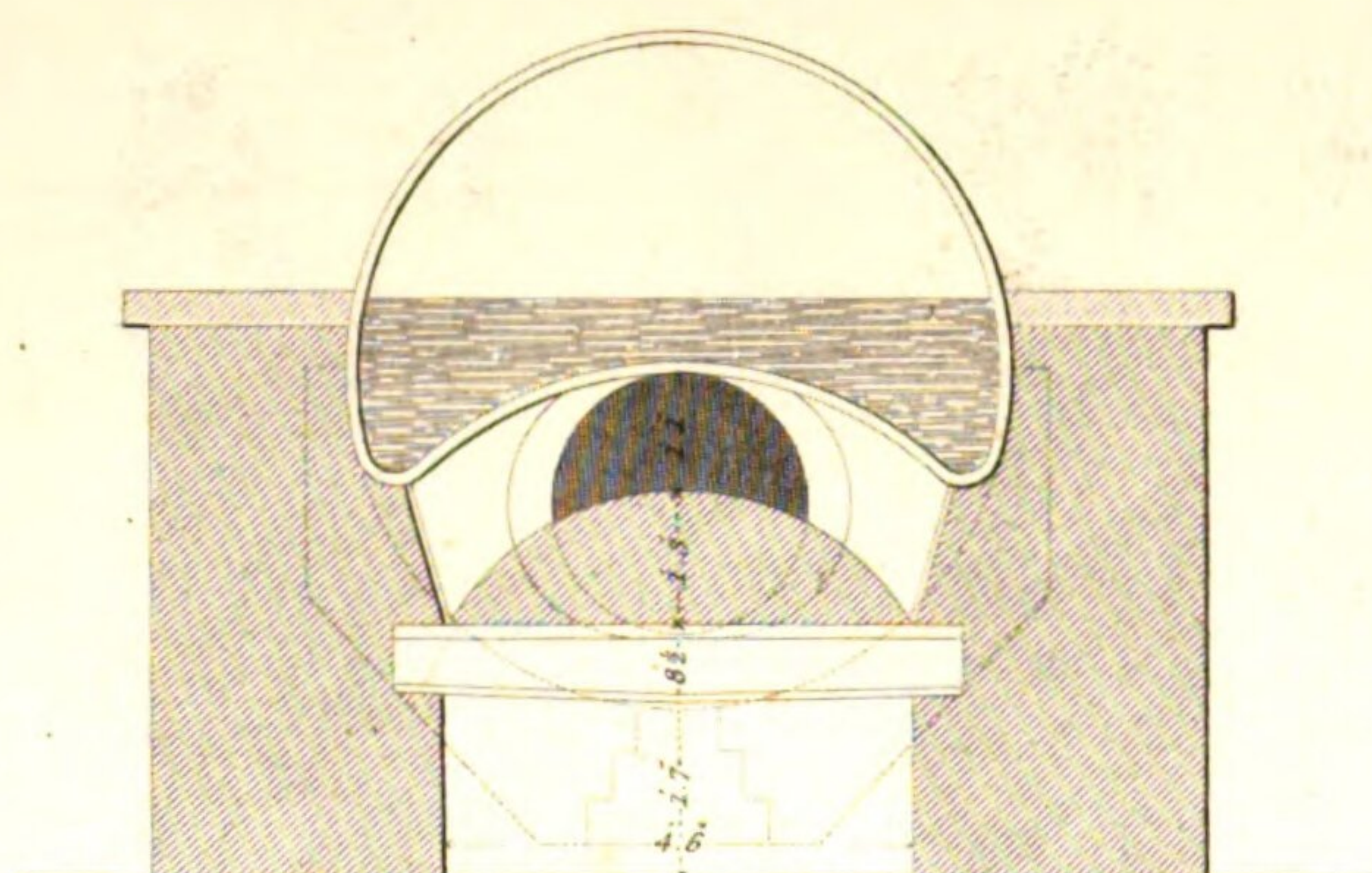
LONGITUDINAL SECTION ON LINE A. B.



PLAN

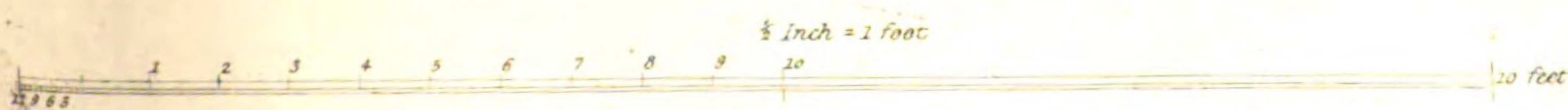


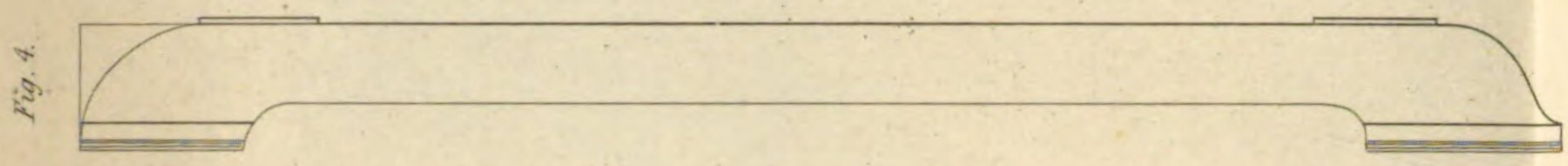
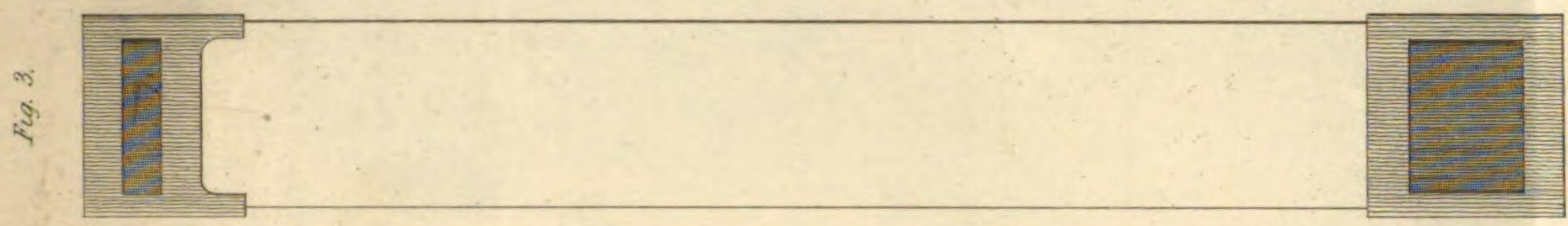
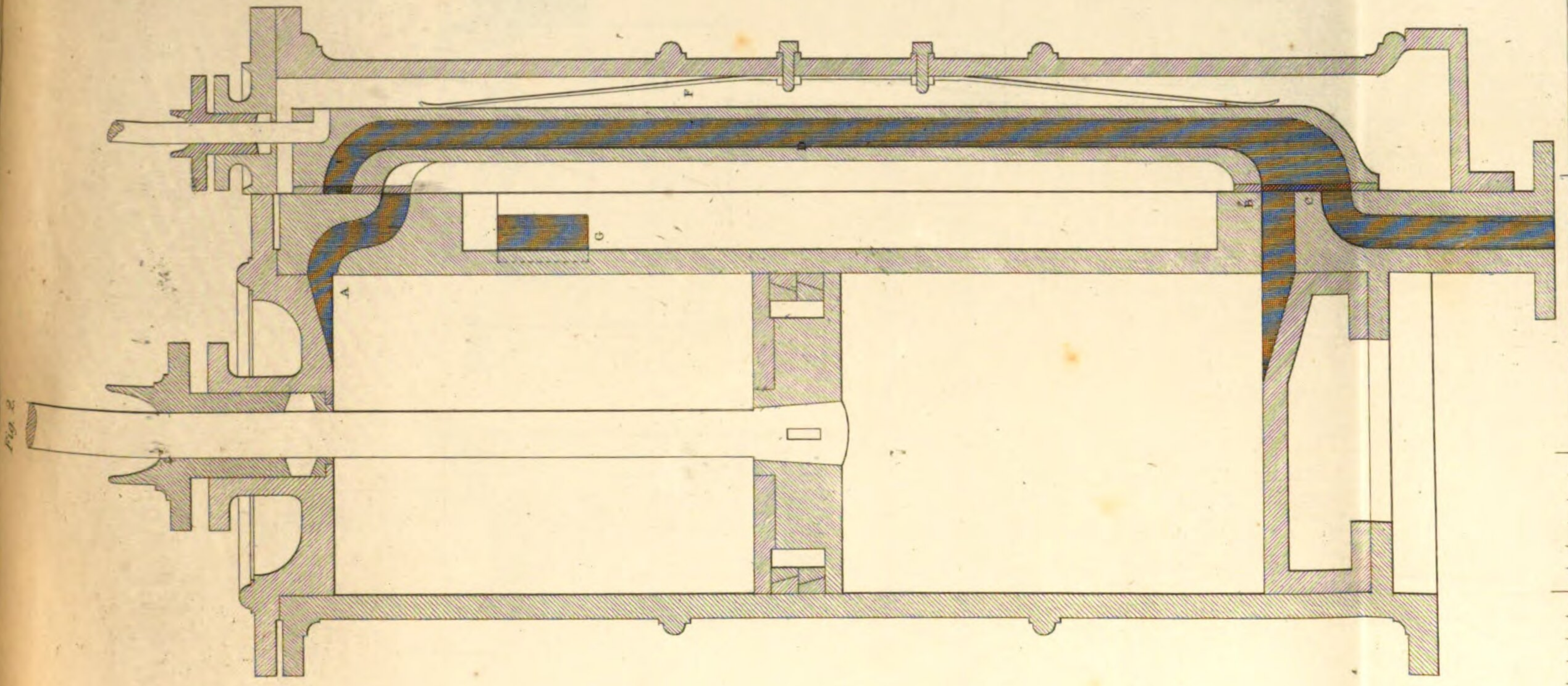
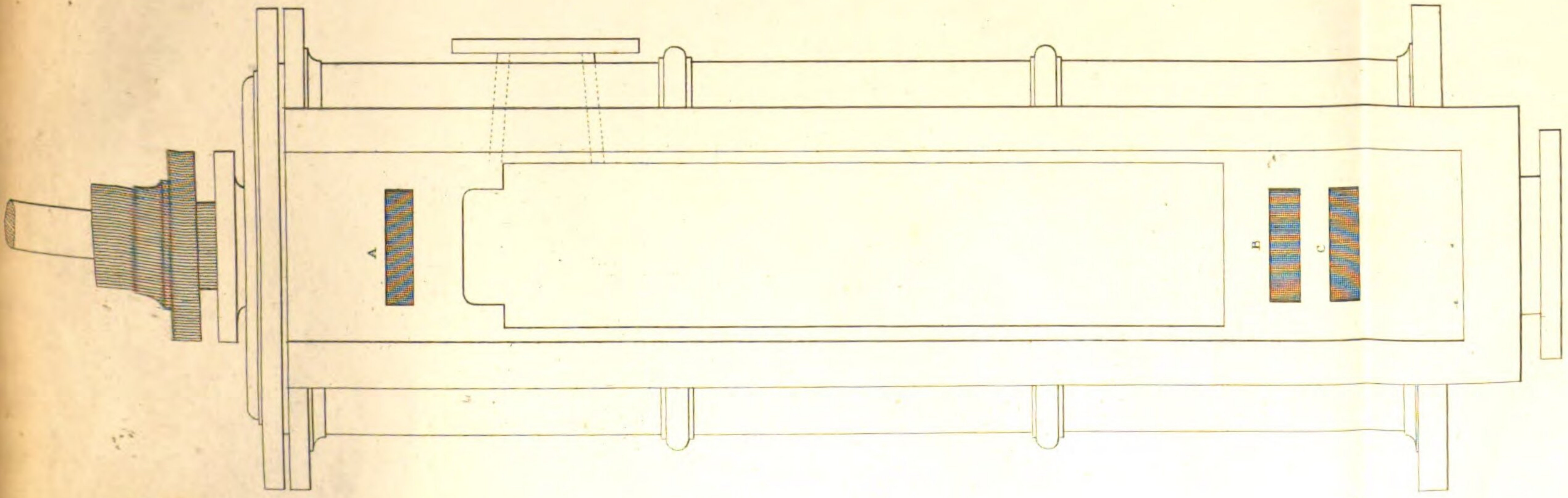
SECTION THROUGH C. D.



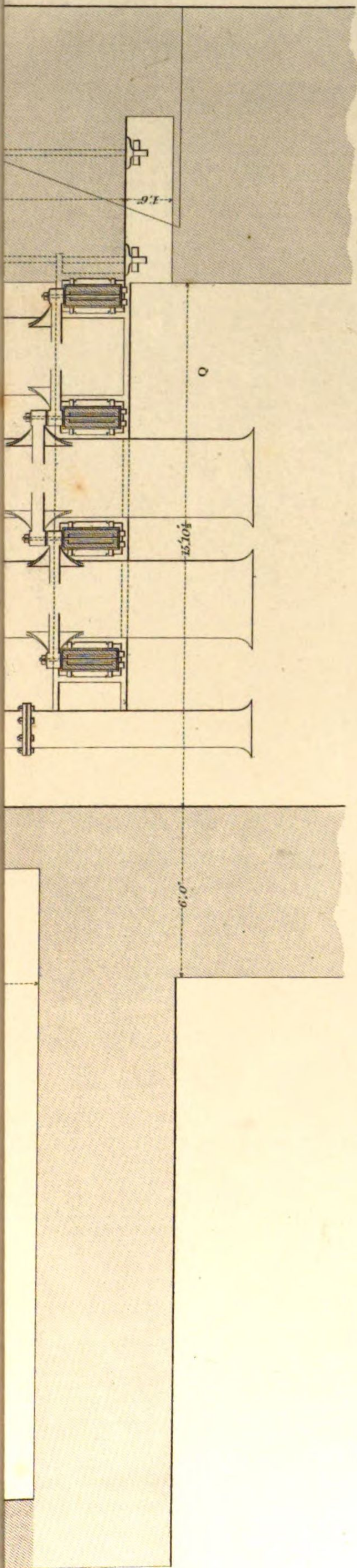
SECTION THROUGH E. F.

T.S. Porter sc

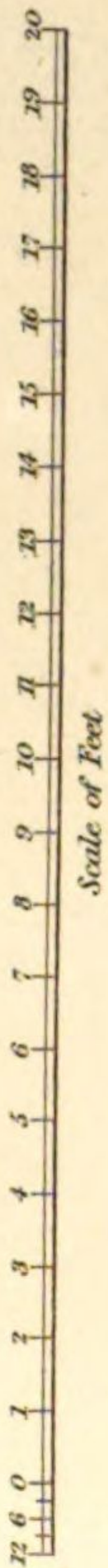


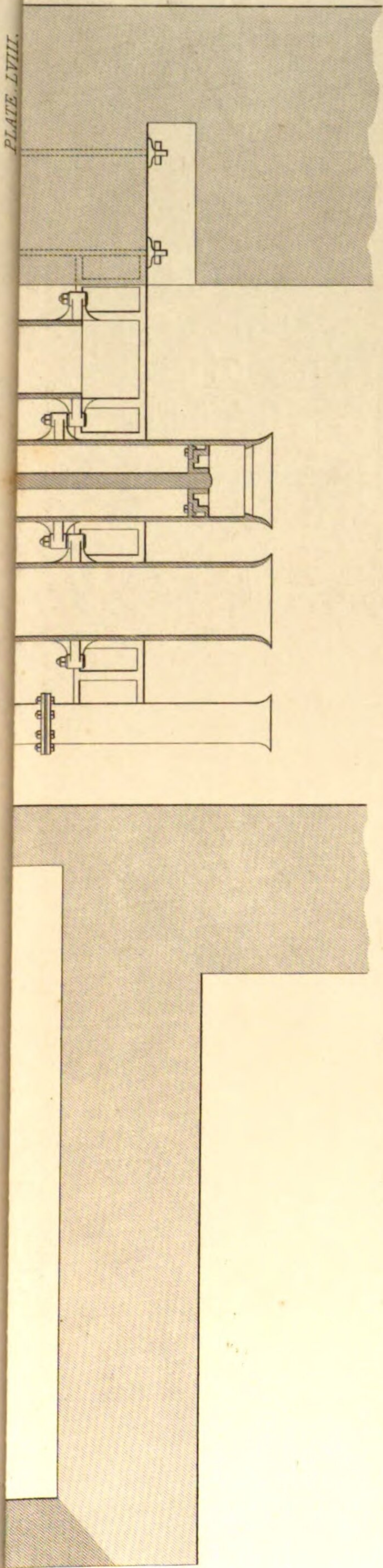


Scale of Feet.

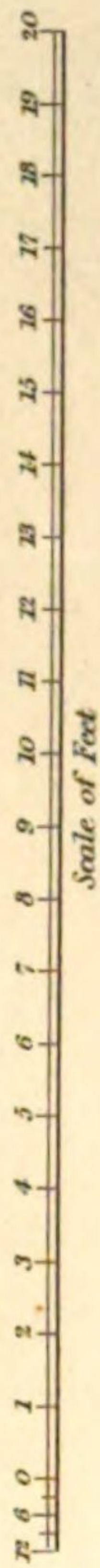


ELEVATION OF THE ENGINE PUMPS AND AIR VESSEL.

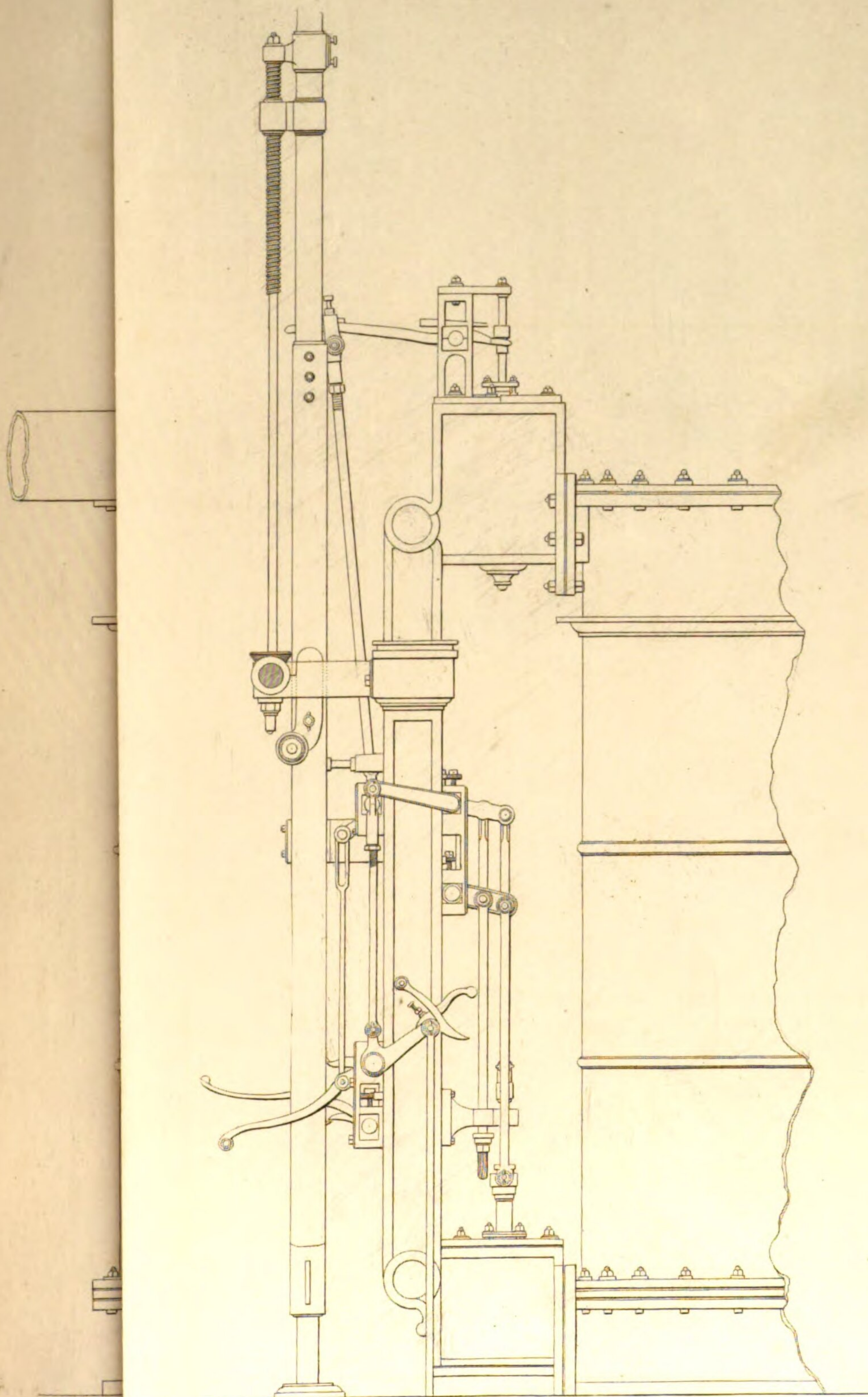




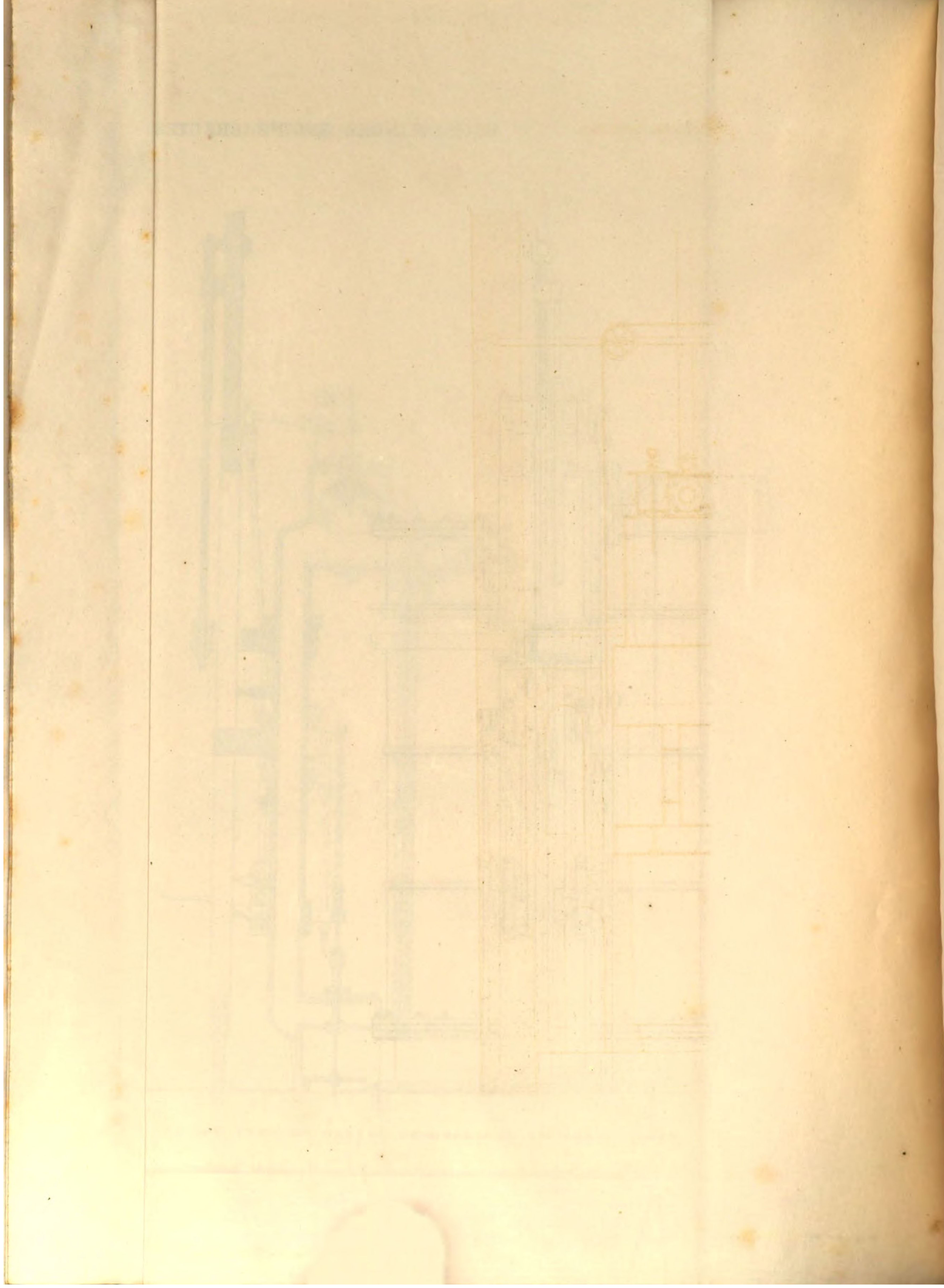
LONGITUDINAL SECTION THROUGH THE CENTRE OF THE CYLINDER, NOZZLES, BEAM, MAIN PUMP &c.



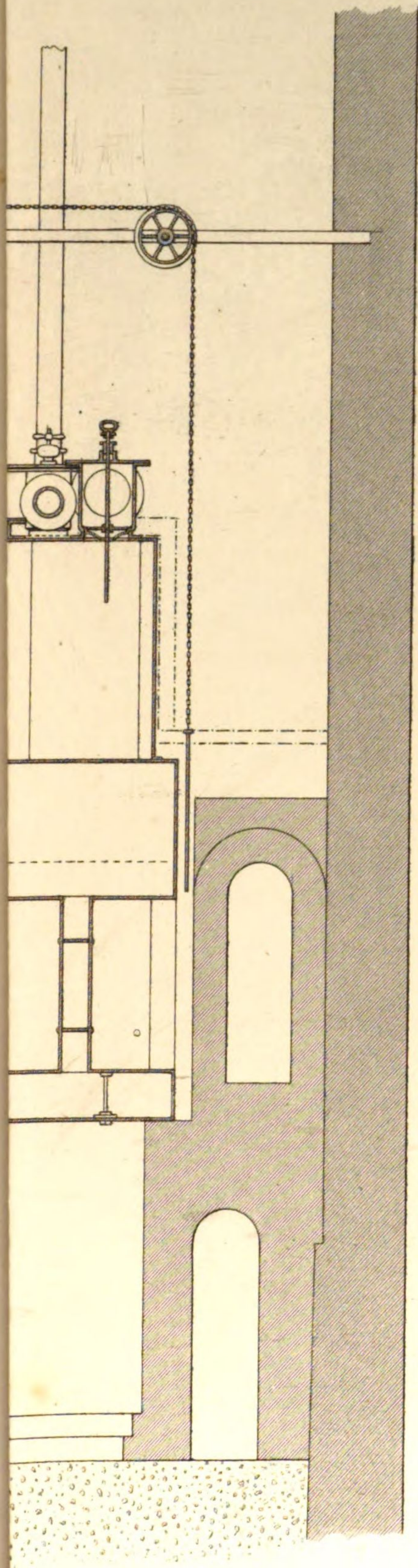
WATER WORKS, 1837.



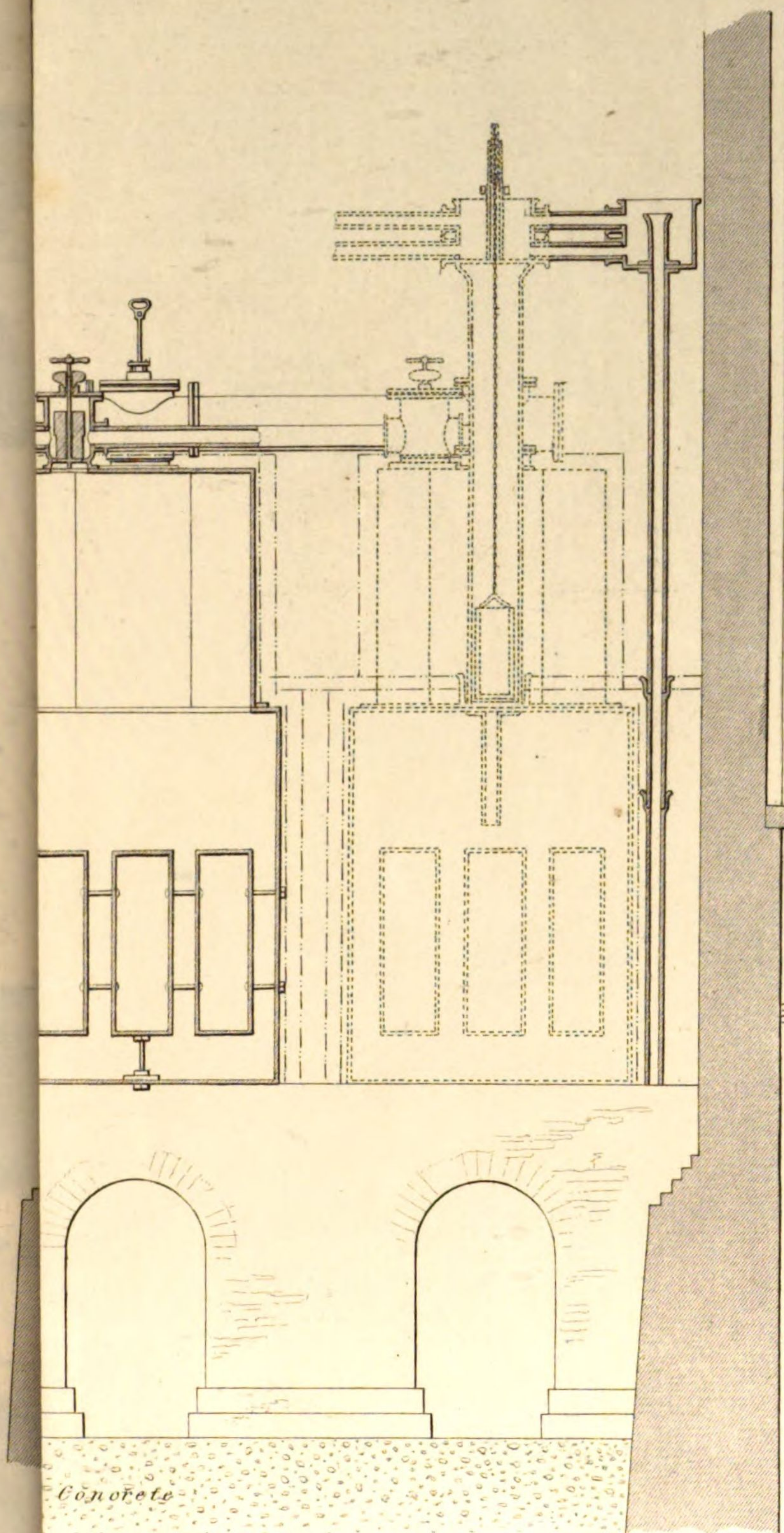
SIDE ELEVATION OF GEARING



WATER WORKS.



SEA WATER WORKS.



ROUGH FEED HEAD SAFETY VALVE, &c.

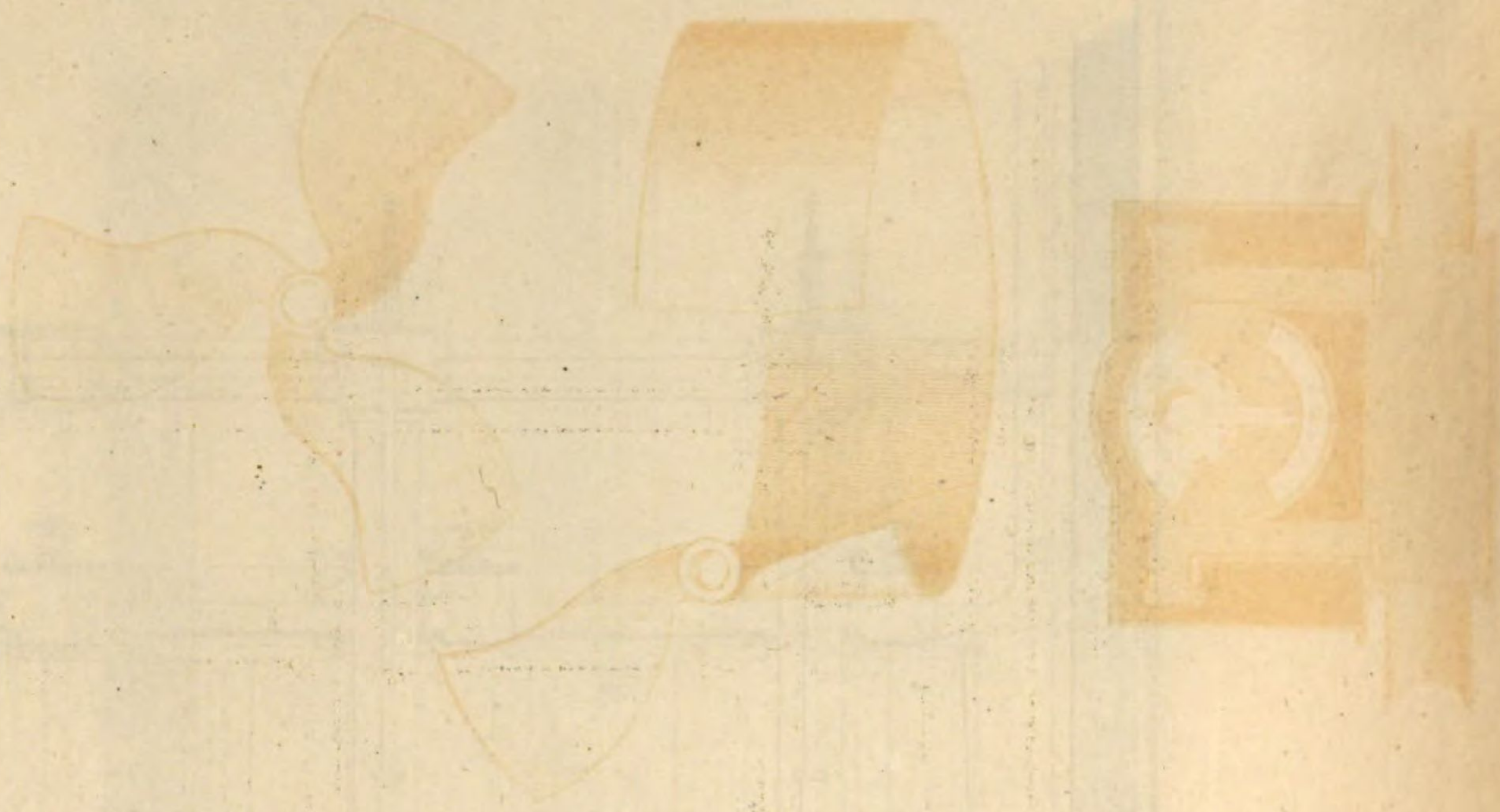


FIG. 1.

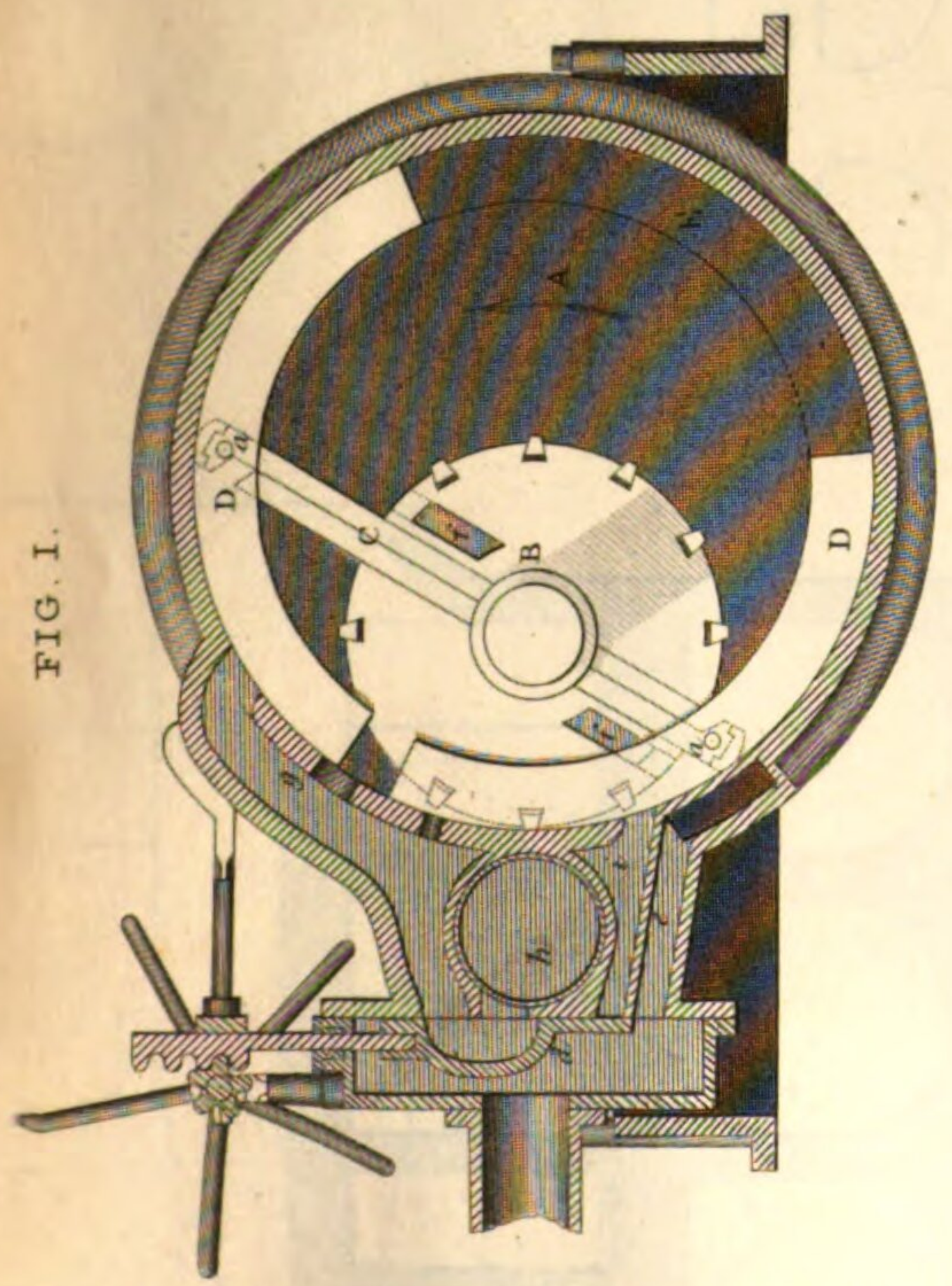


FIG. 2.

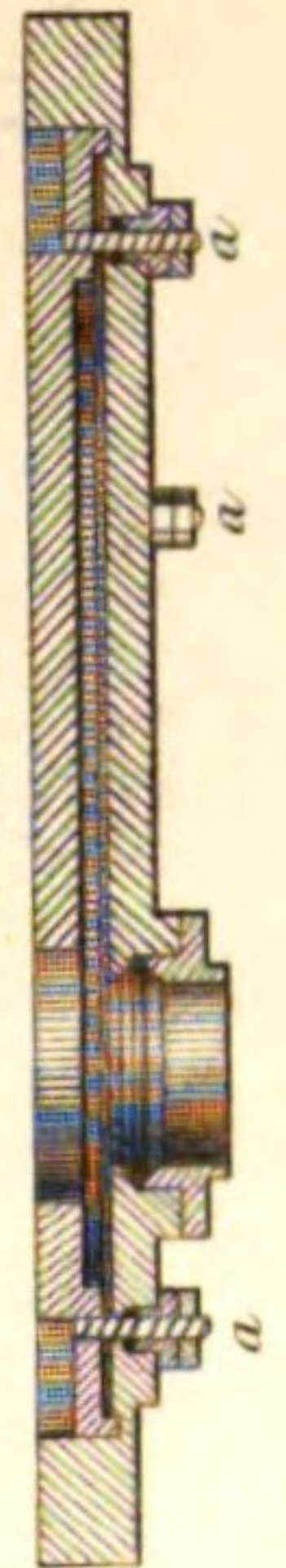


FIG. 3.

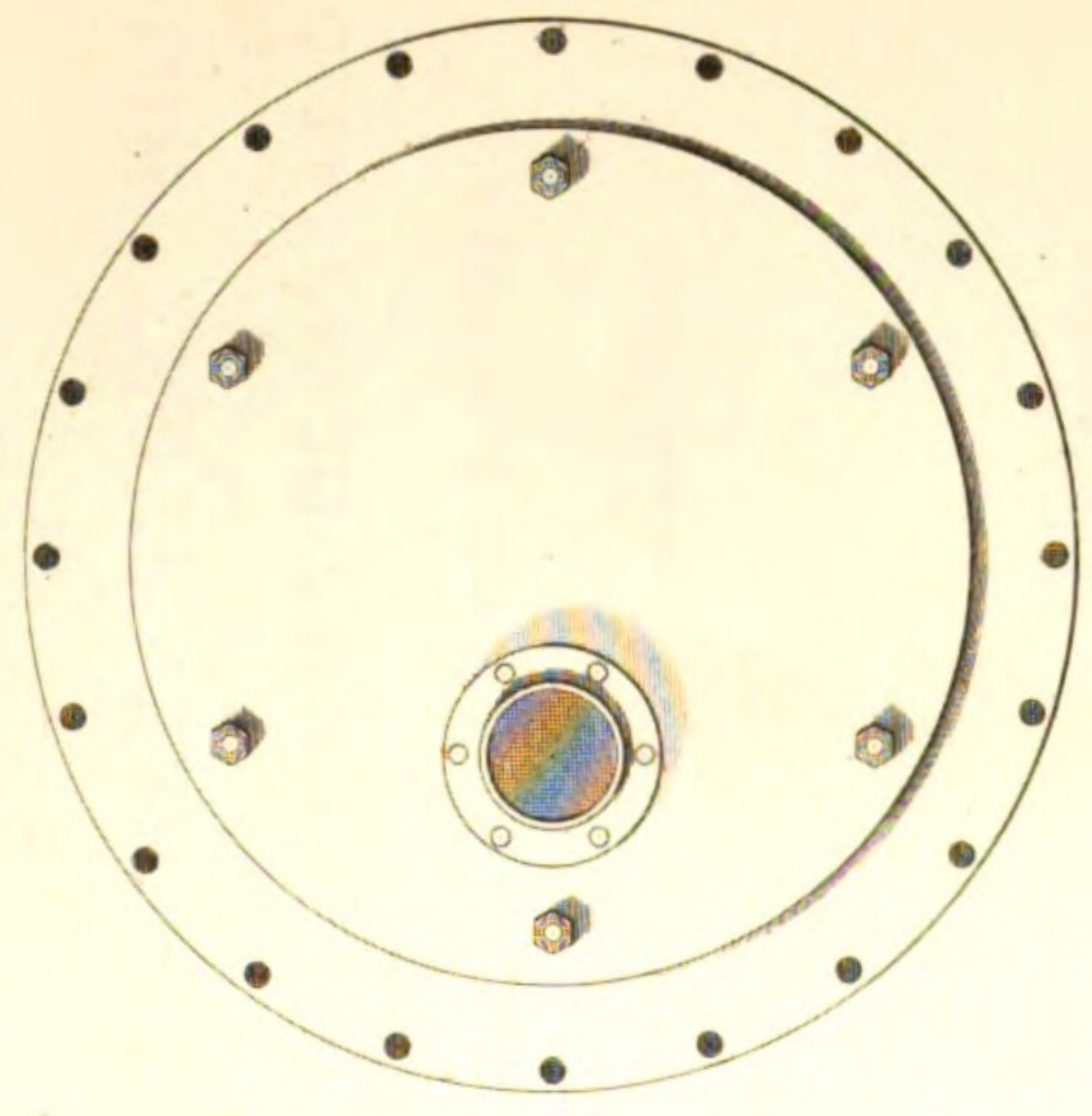
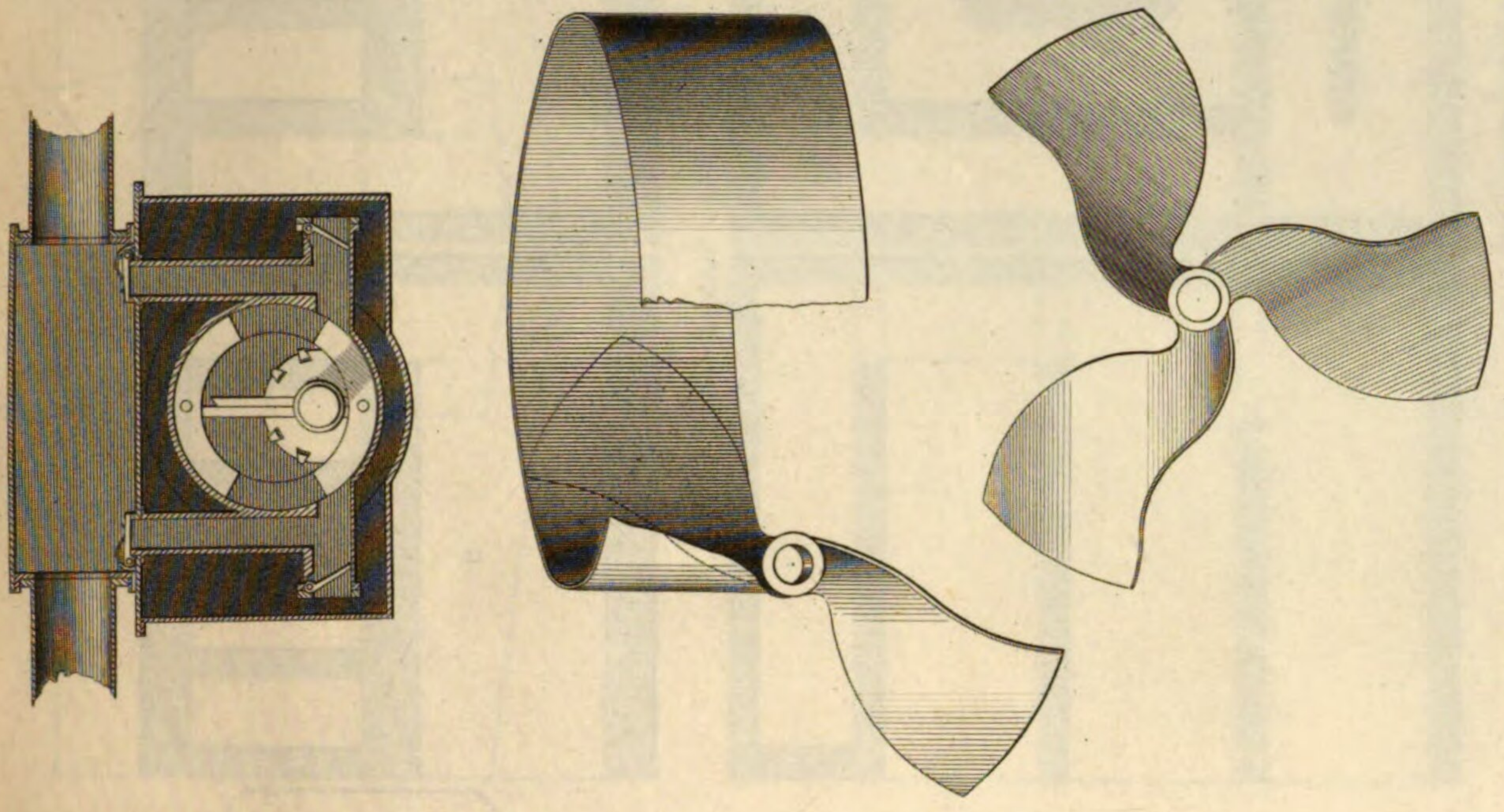
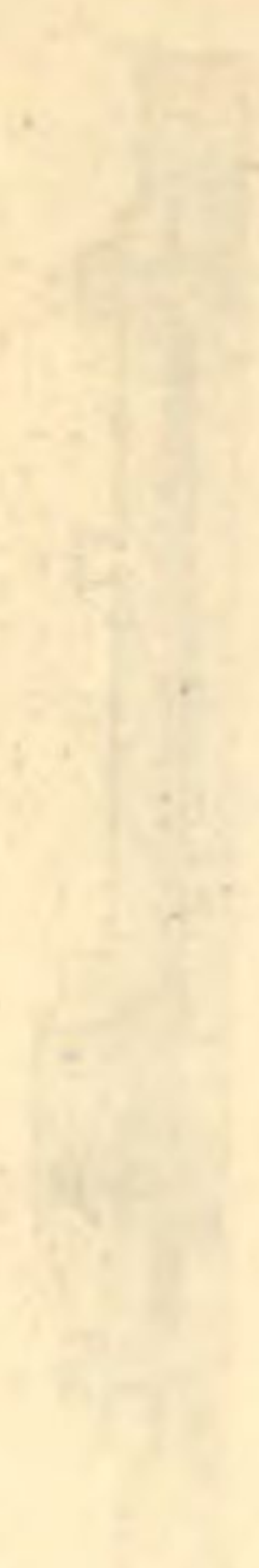
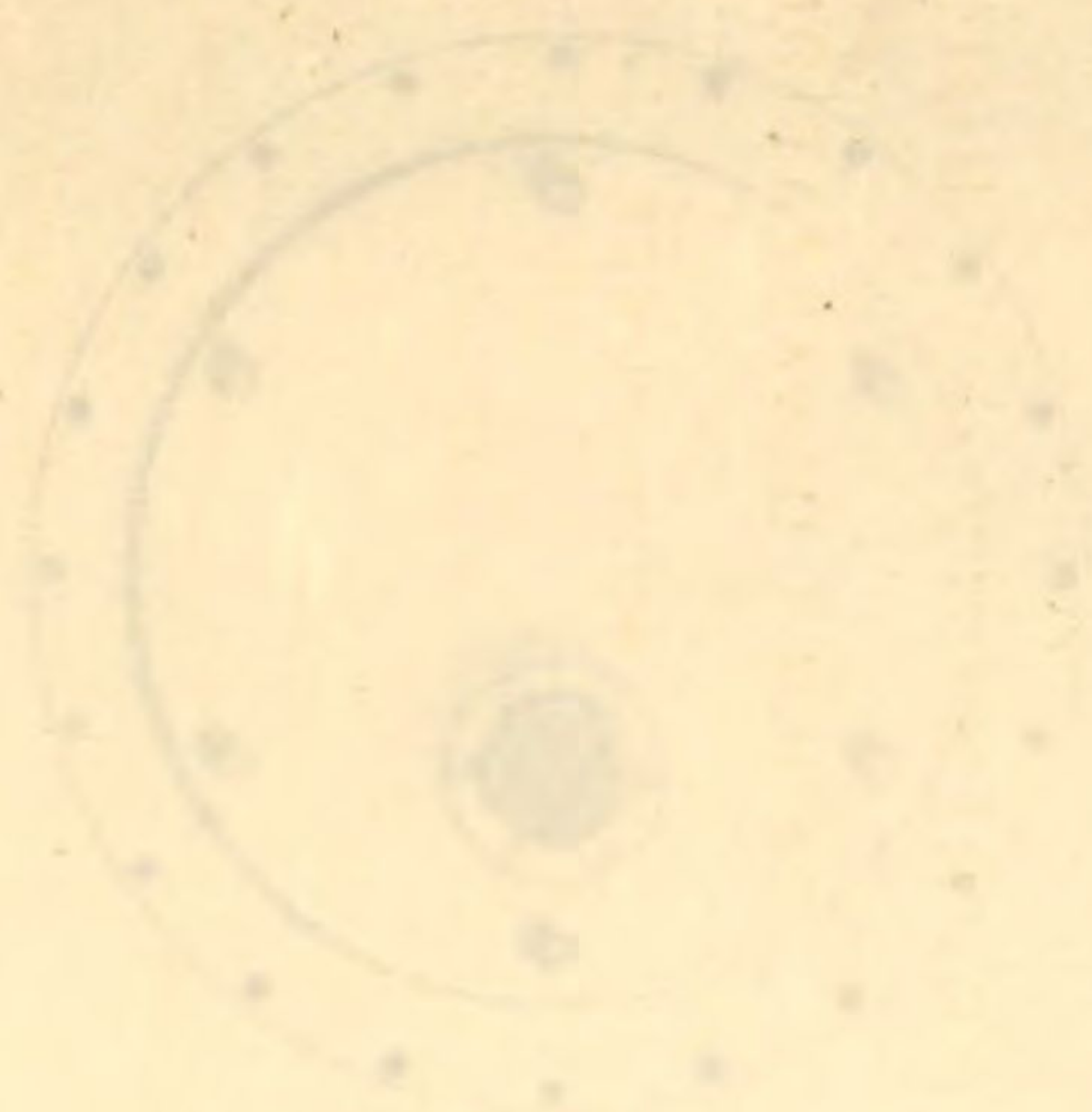
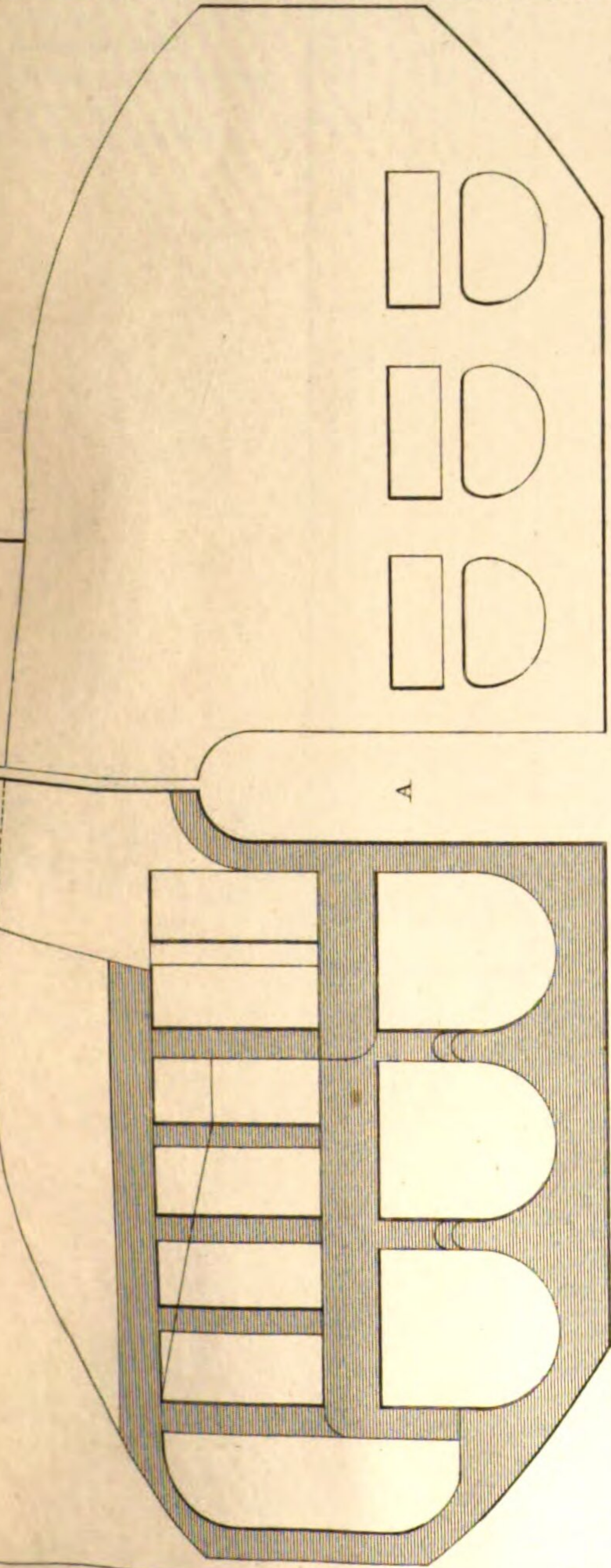


FIG. 4.

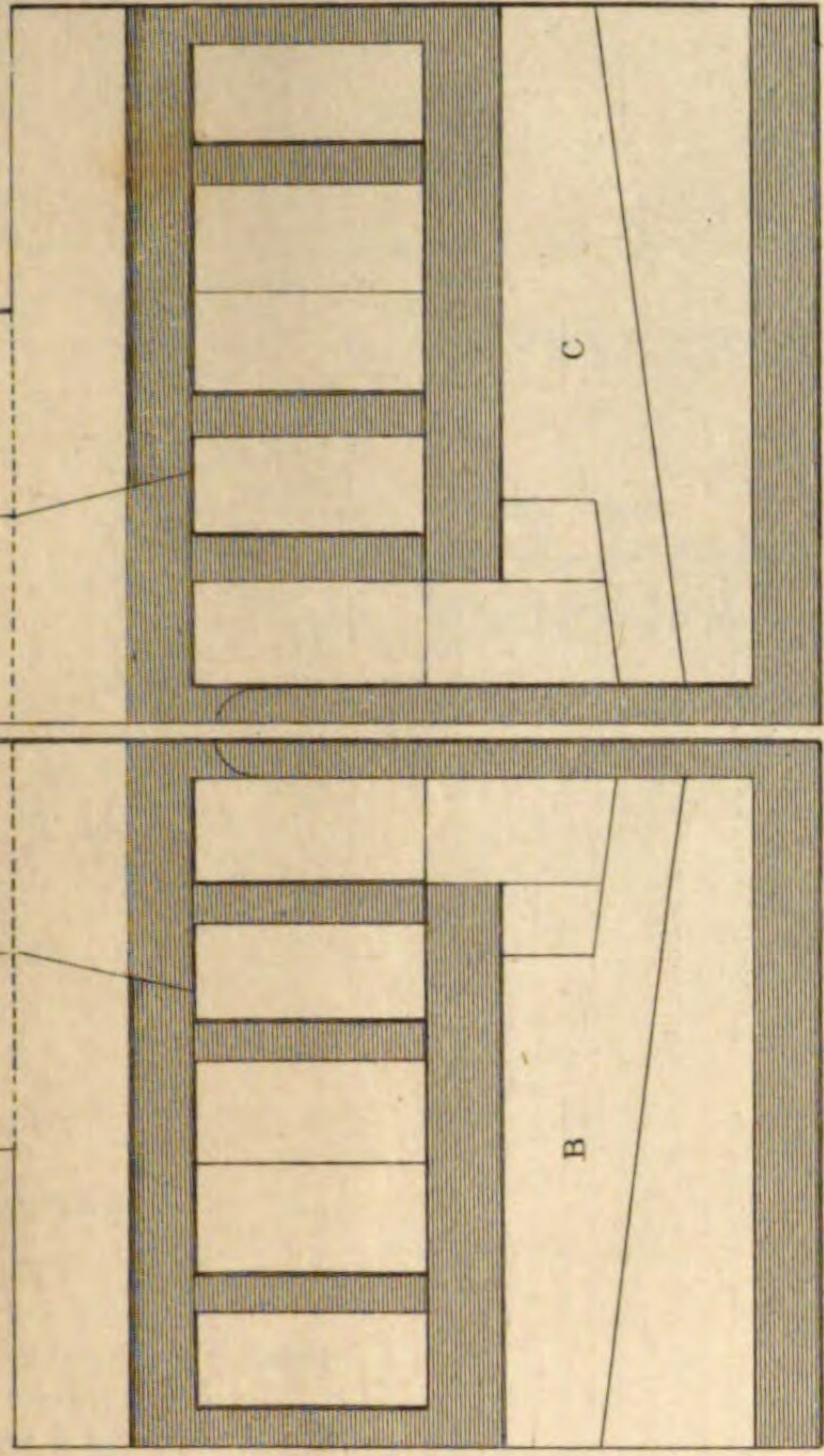




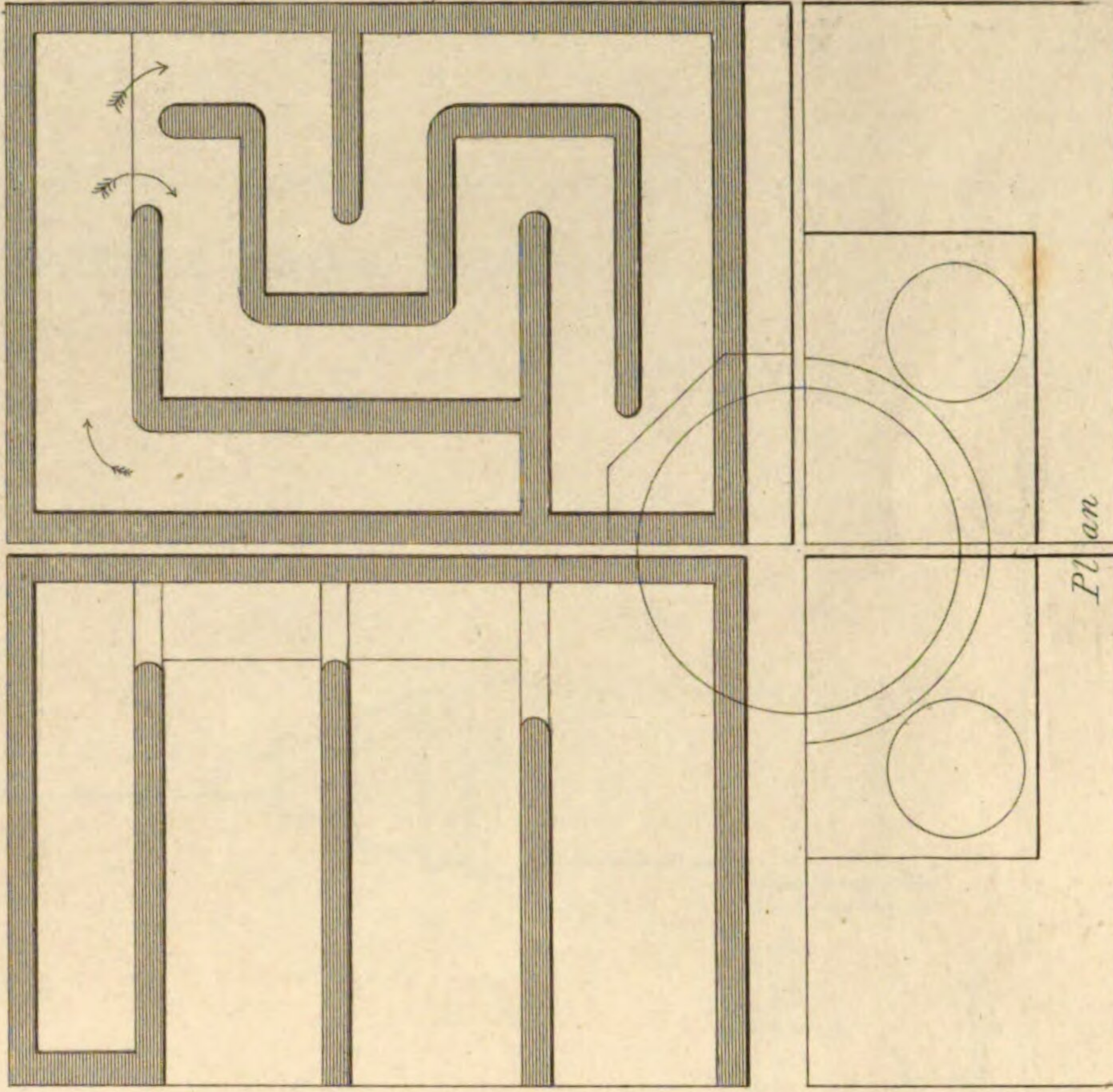
Front Elevation.



Longitudinal Section.



Horizontal Section.



DOUBLE STORY BOILERS.

OF H.M.S. DEVASTATION.

400 H. POWER.

$\frac{1}{4}$ inch Scale.

Reference.

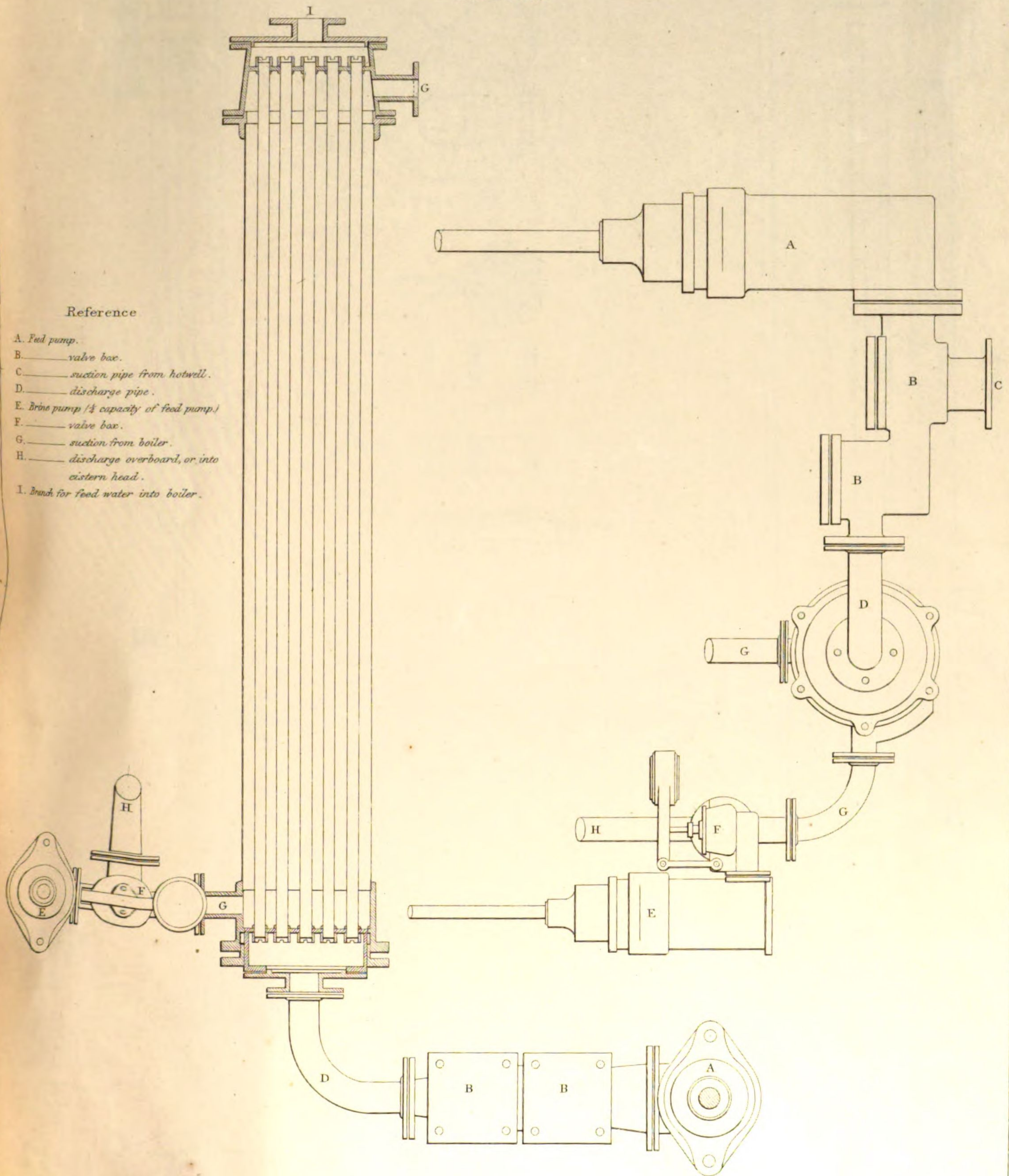
- A. Passage between the Boilers from the Fore to the After Stoke Hole.
- B. Furnaces of the Fore Stoke Hole.
- C. Furnaces of the After Stoke Hole.

REFRIGERATOR FEED & BRINE PUMPS.

1 inch Scale.

Reference

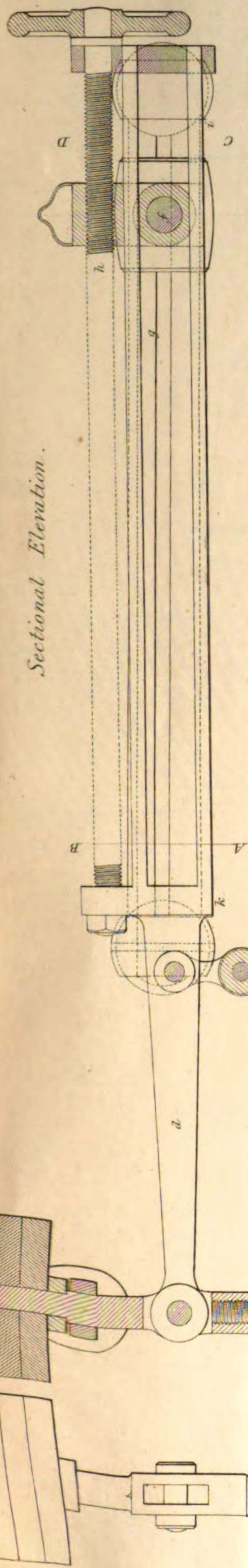
- A. Feed pump.
- B. valve box.
- C. suction pipe from hotwell.
- D. discharge pipe.
- E. Brine pump (1/4 capacity of feed pump.)
- F. valve box.
- G. suction from boiler.
- H. discharge overboard, or into cistern head.
- I. branch for feed water into boiler.



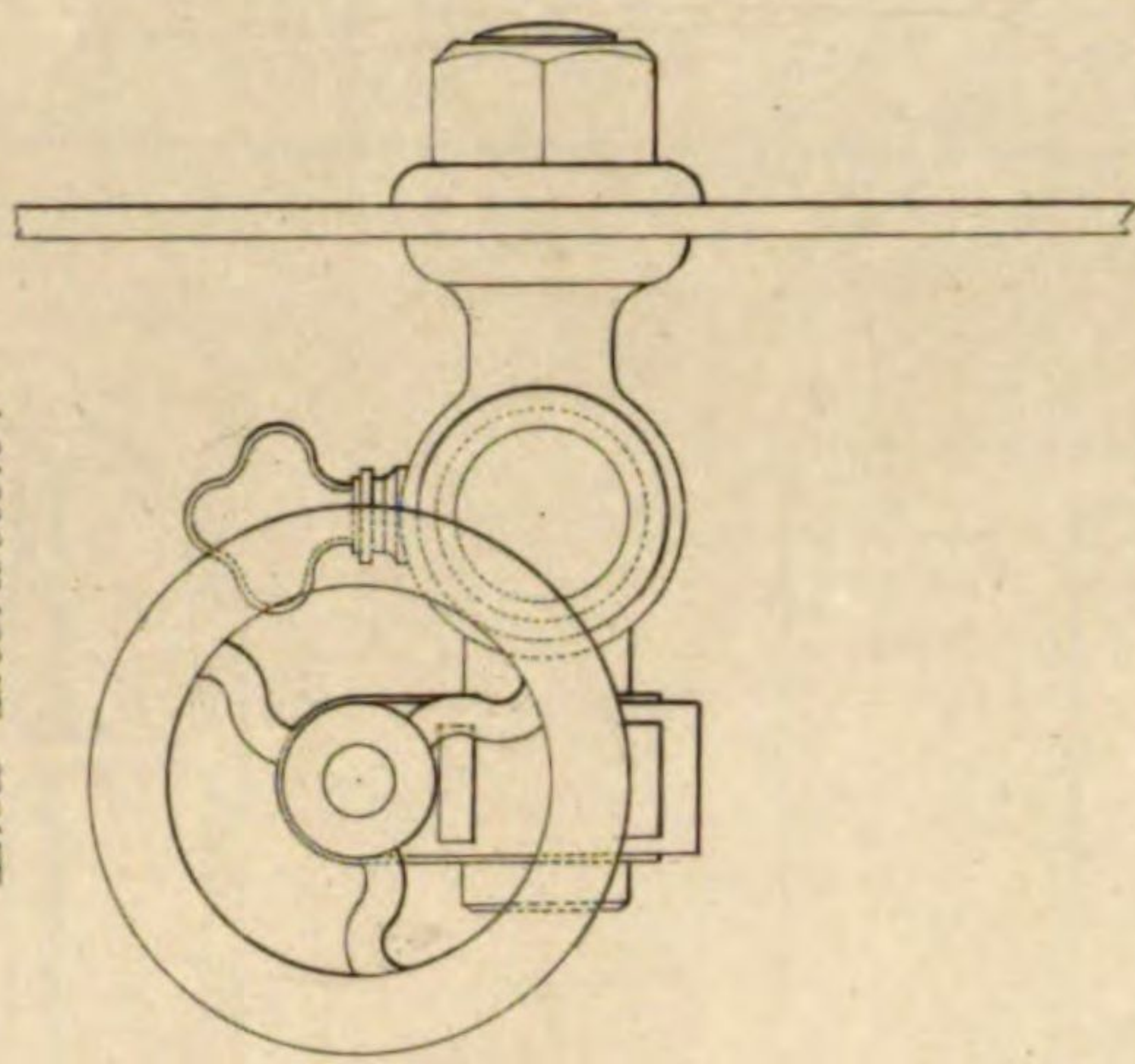
FEEB & BRINE APPARATUS. AS FITTED ON BOARD THE WEST INDIA ROYAL MAIL CO'S SHIPS.

To be weighed 3 lb above
the pressure in the boiler

Sectional Elevation.

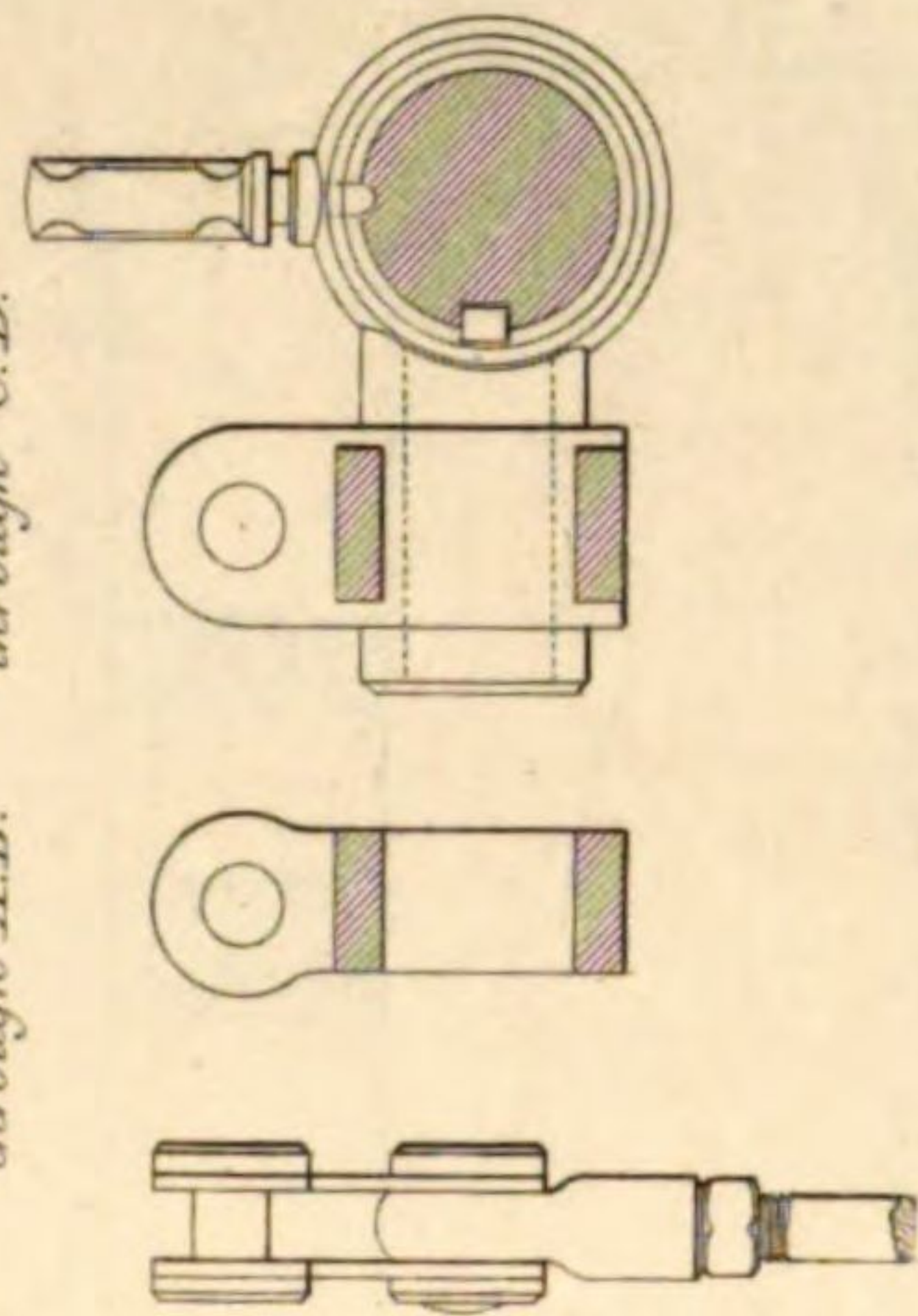


End Elevation.



Sections.

through A.B. through C.D.

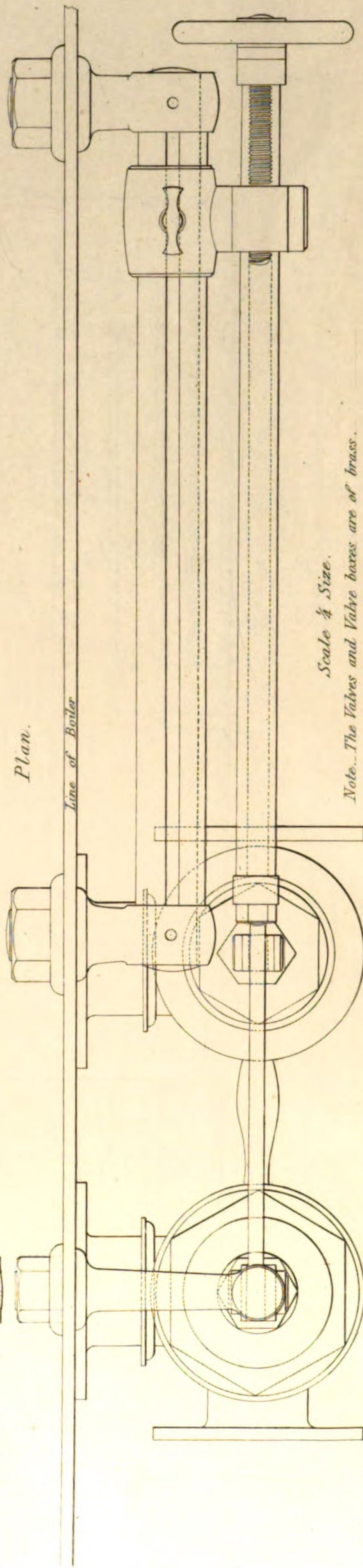


BRINE VALVE

FEED VALVE

Plan.

Line of Boiler

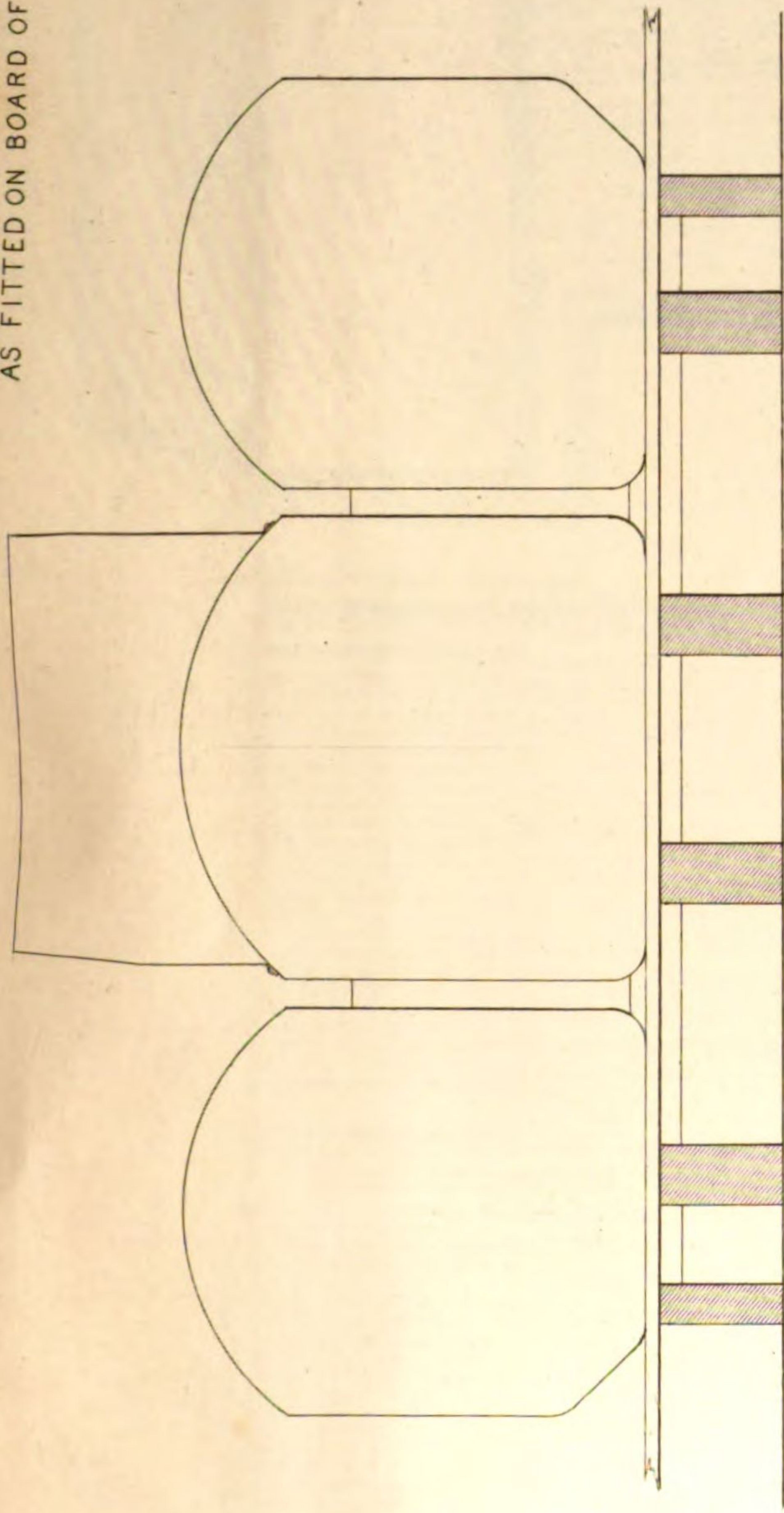


Scale 1/4 Size.

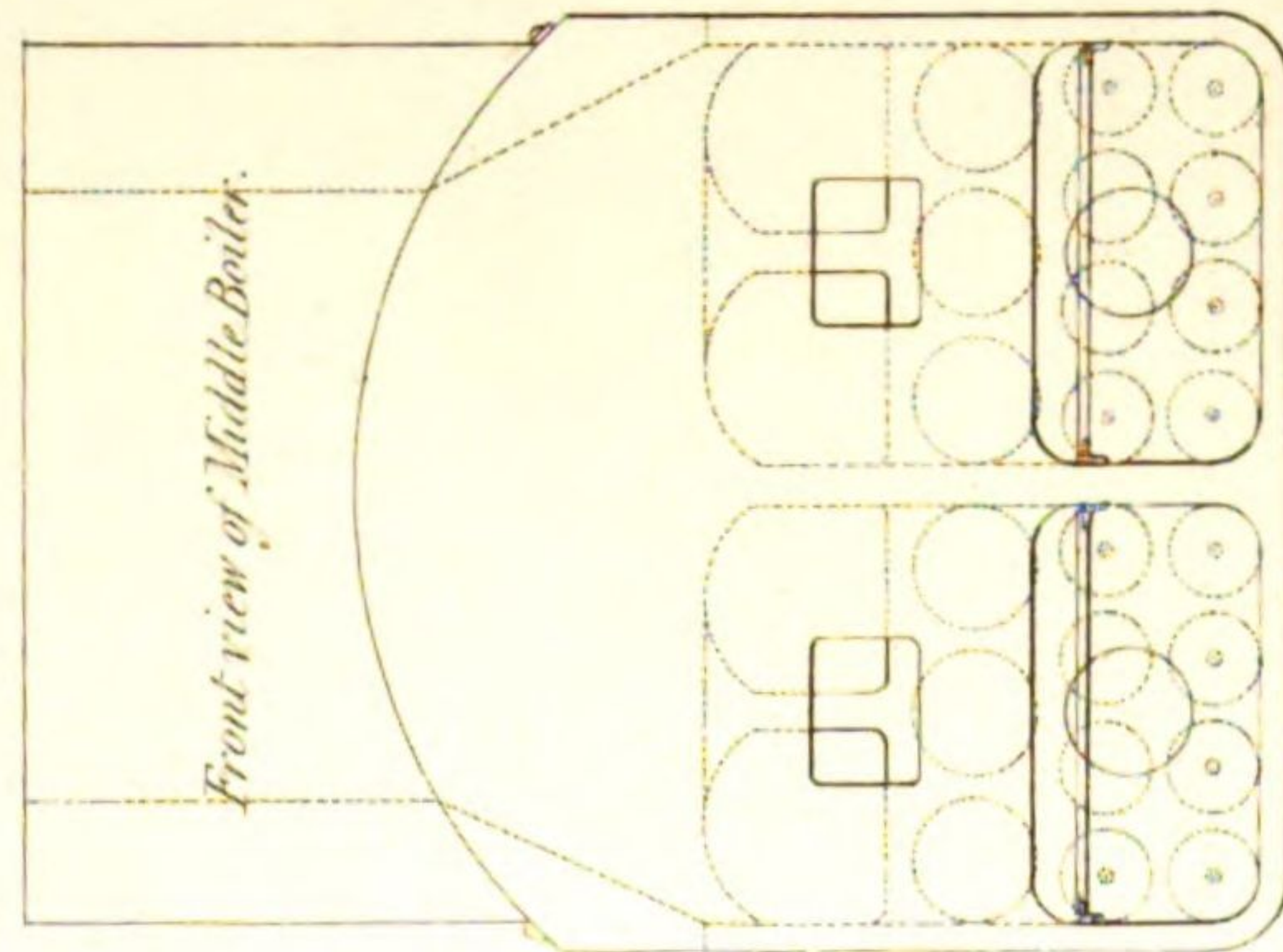
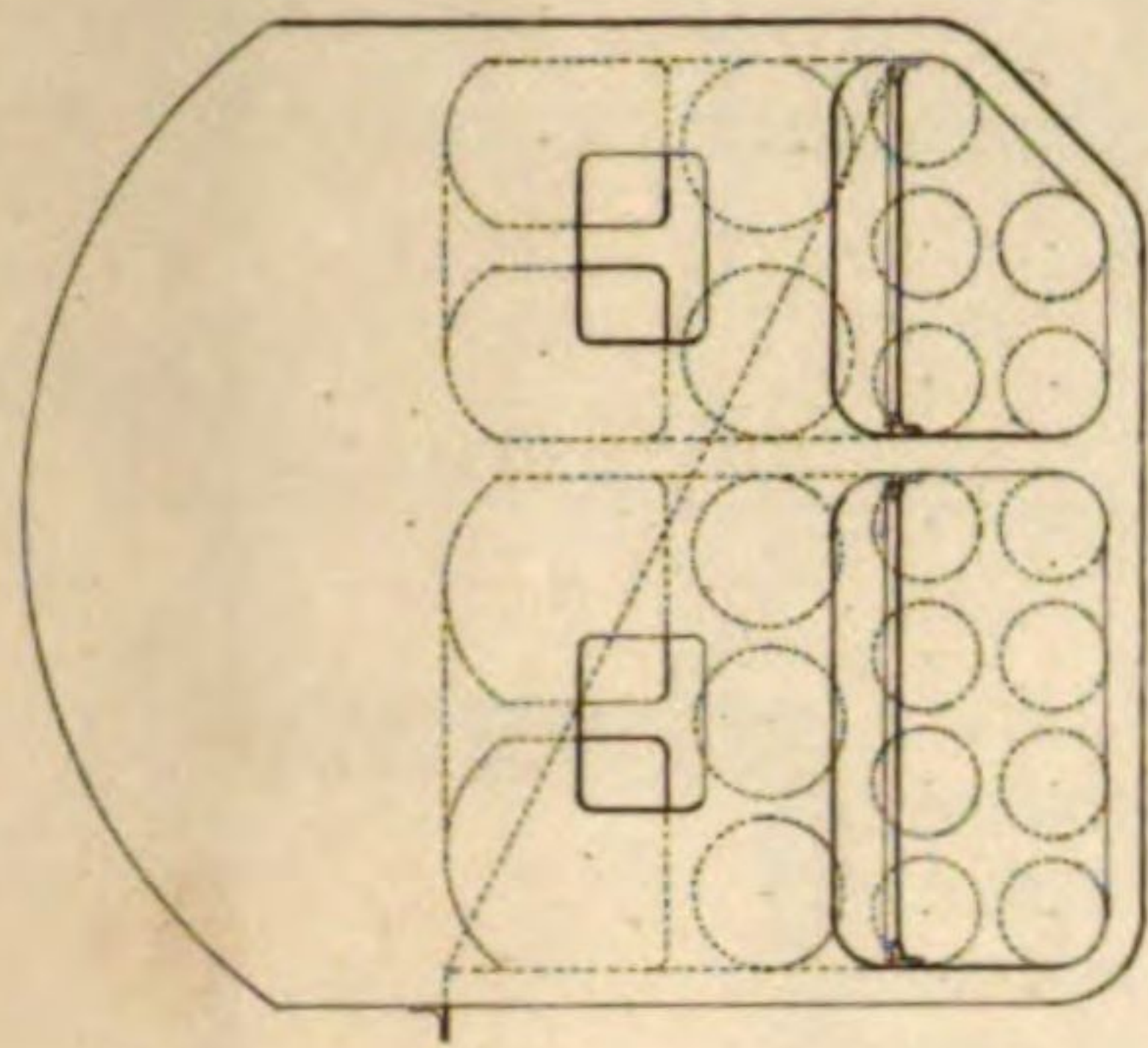
Note. The Valves and Valve boxes are of brass.

AMERICAN MARINE BOILERS.

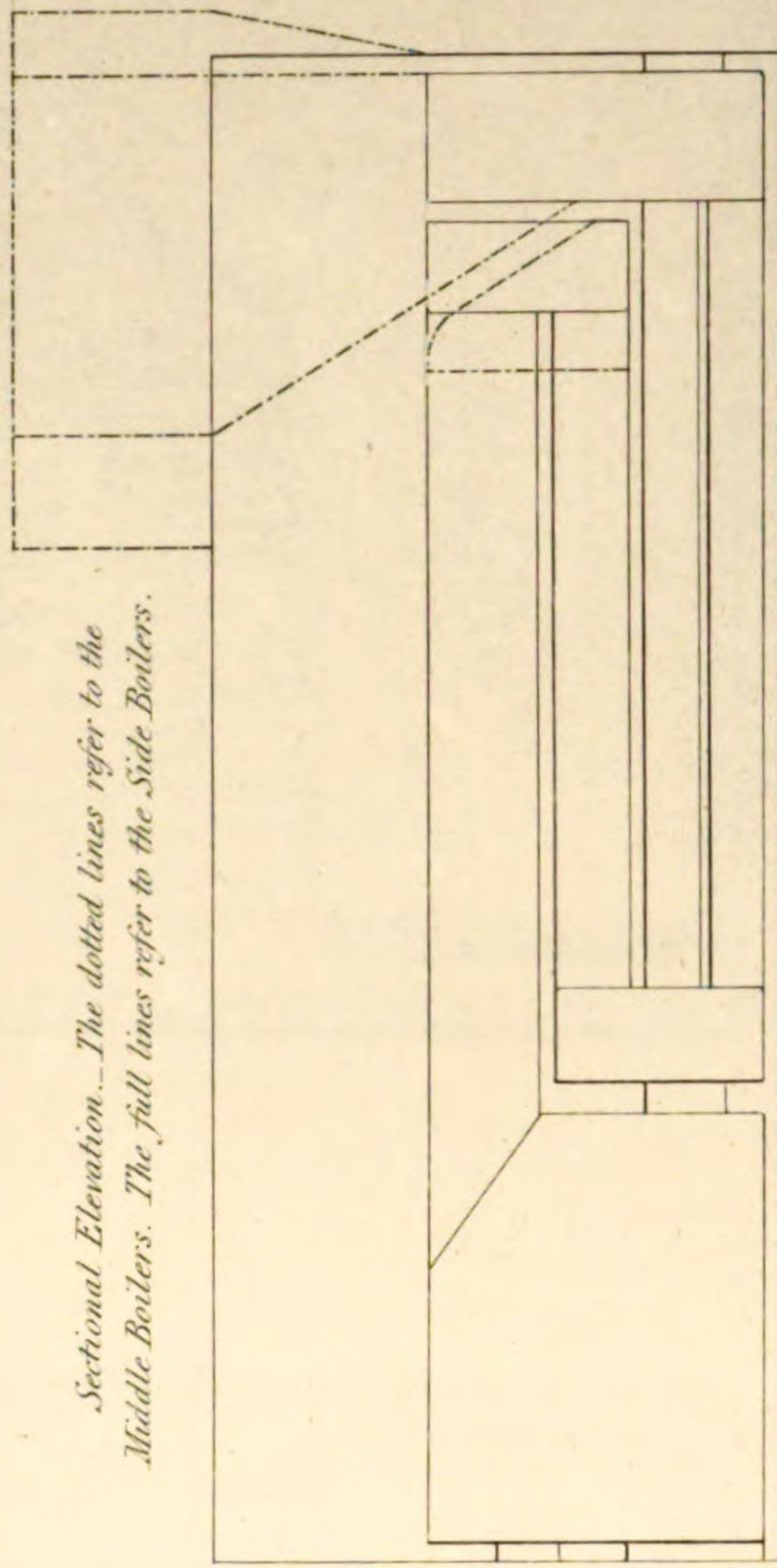
Designed & Executed by C.W. Copeland Esq. Engineer of New York.
AS FITTED ON BOARD OF THE AMERICAN PACKETS.



Front view of Side Boilers.



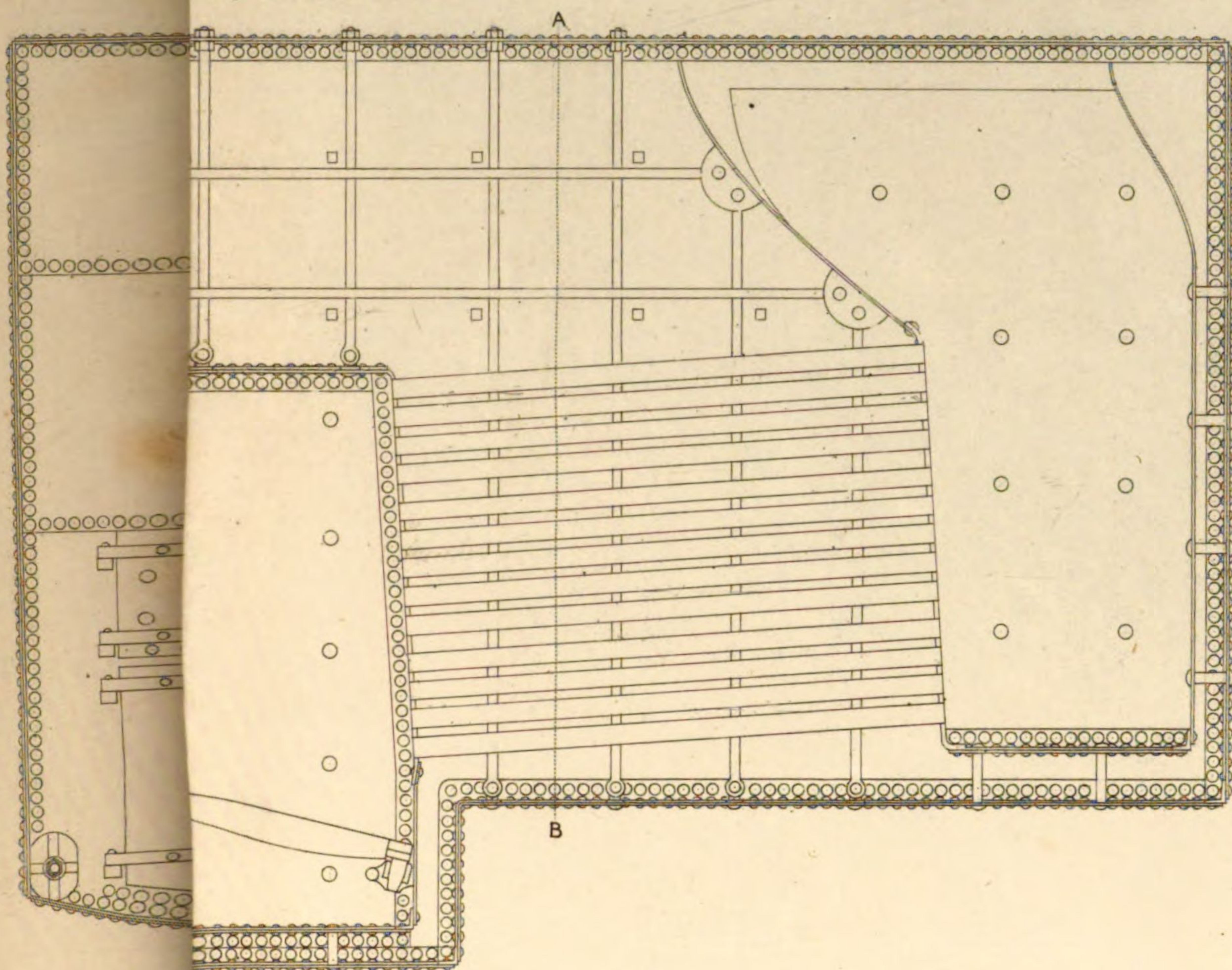
Front view of Middle Boiler.



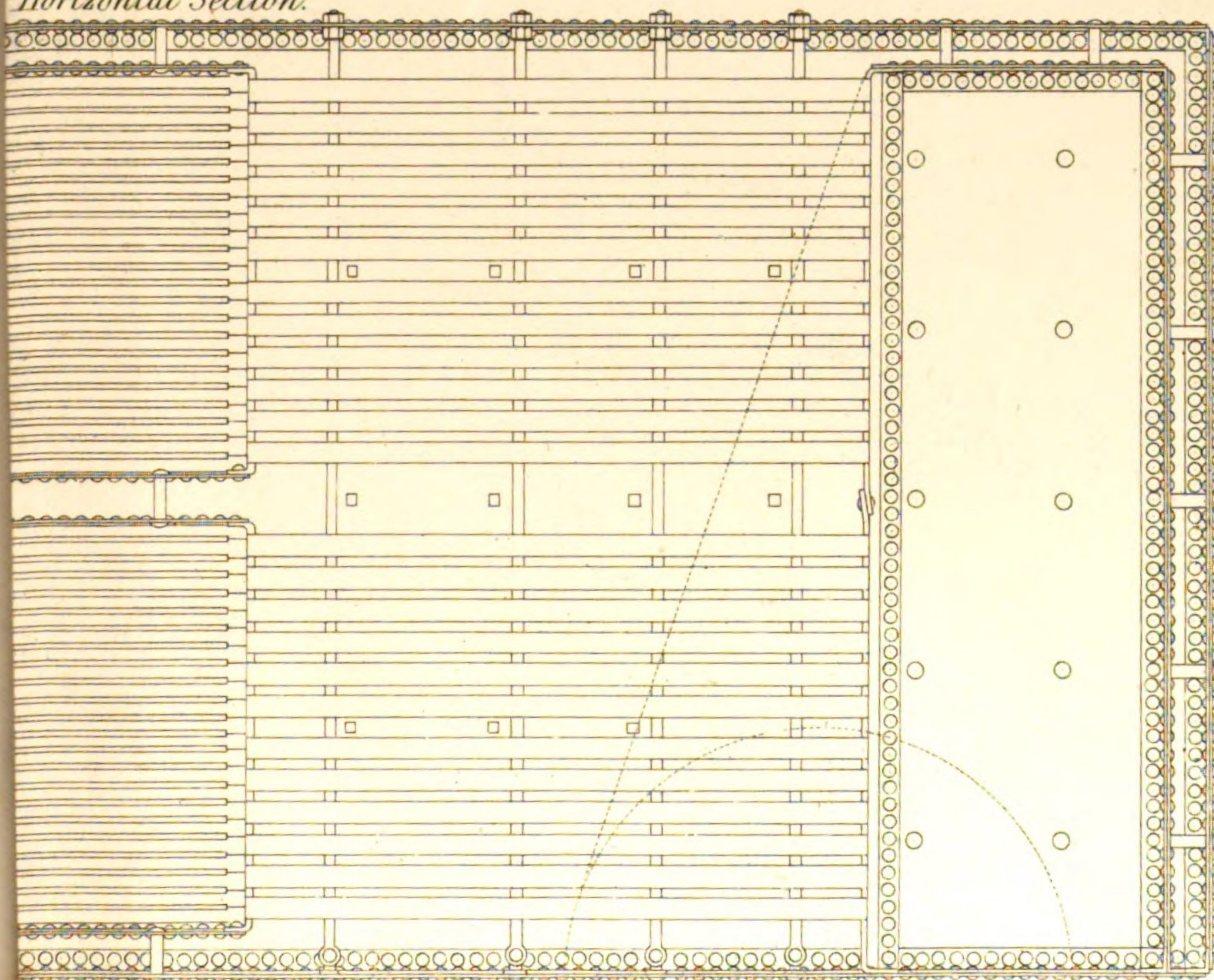
Sectional Elevation... The dotted lines refer to the Middle Boilers. The full lines refer to the Side Boilers.

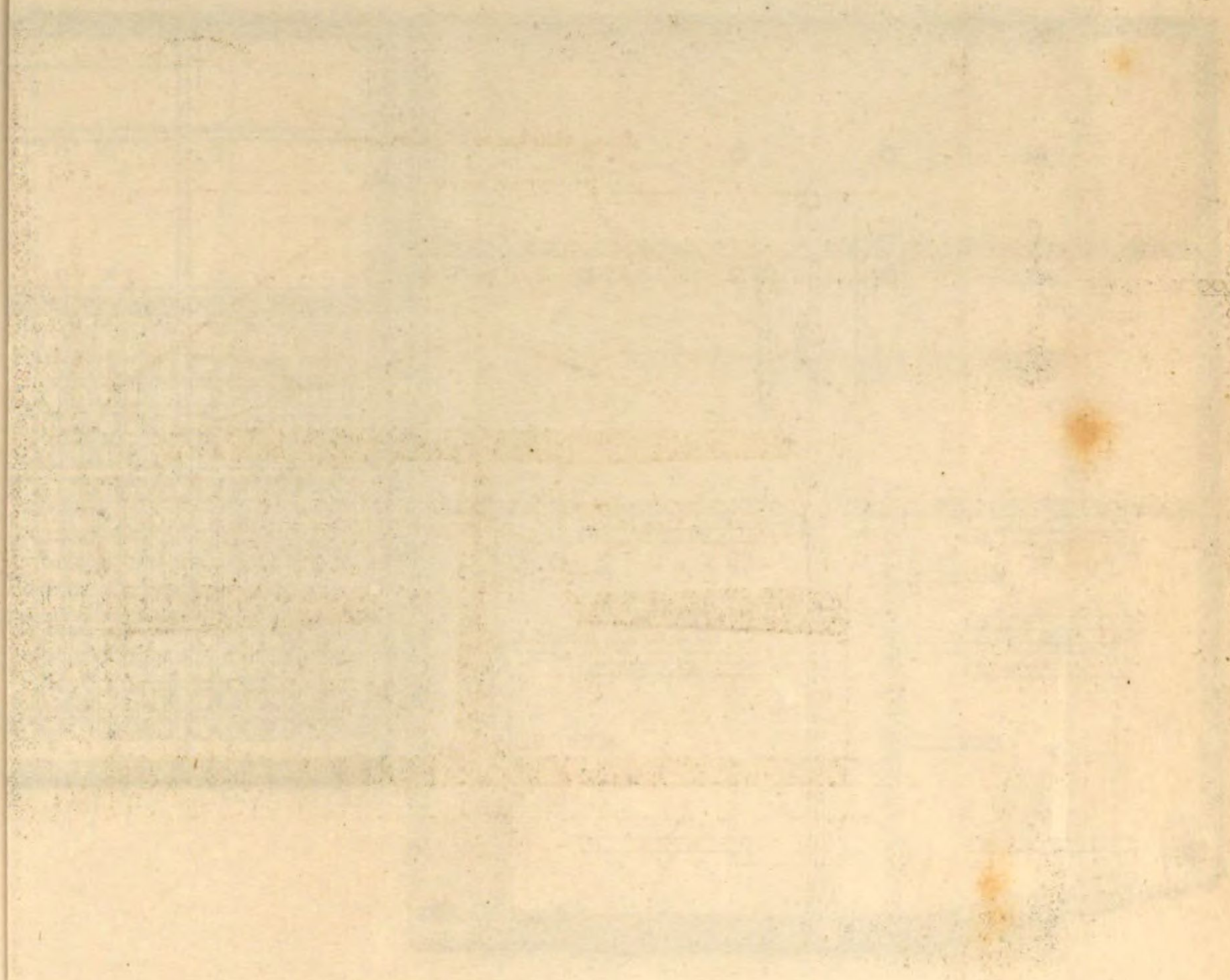
Scale $\frac{1}{16}$ in = 1 foot.

Longitudinal Section.



Horizontal Section.

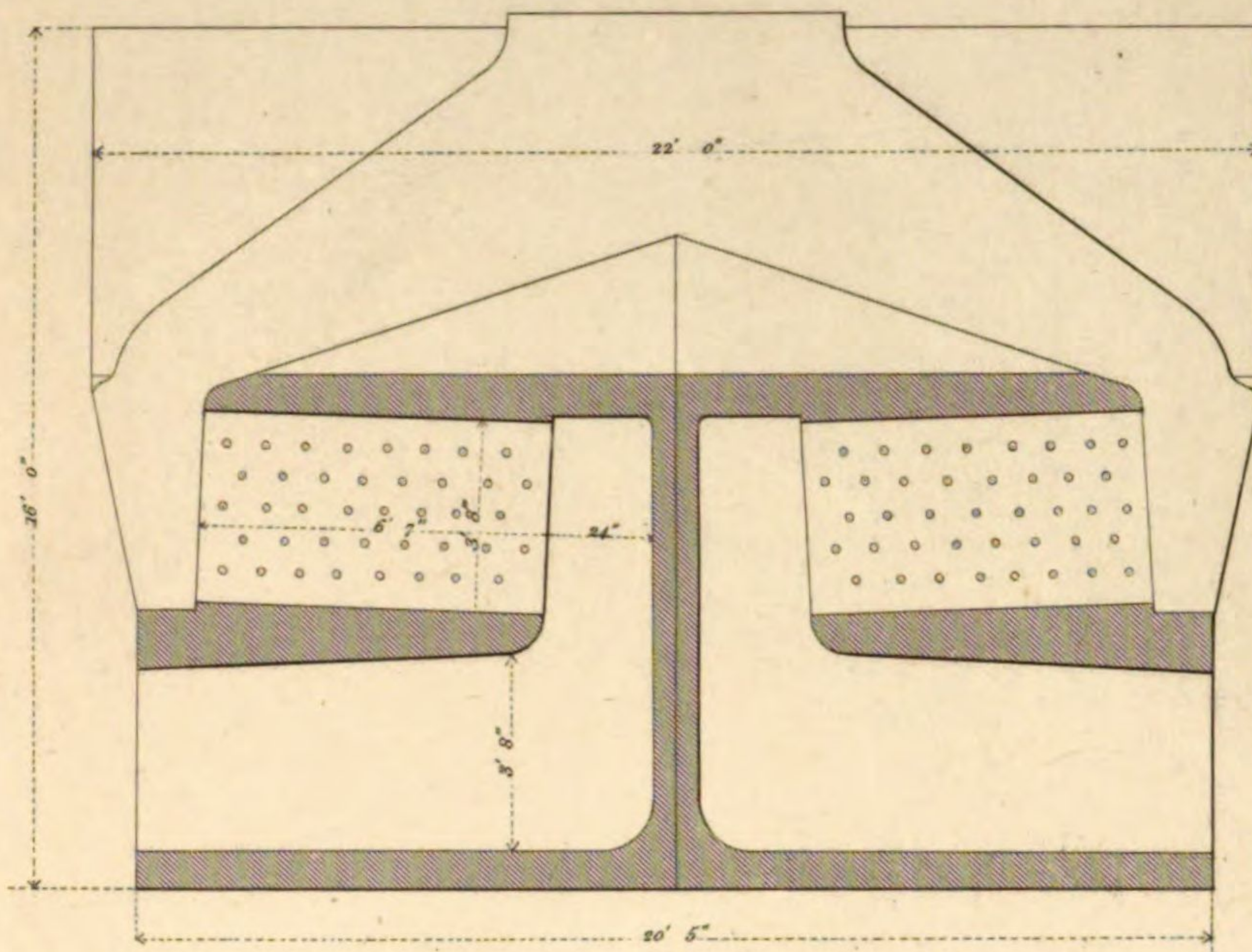




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RS.

Longitudinal Section.



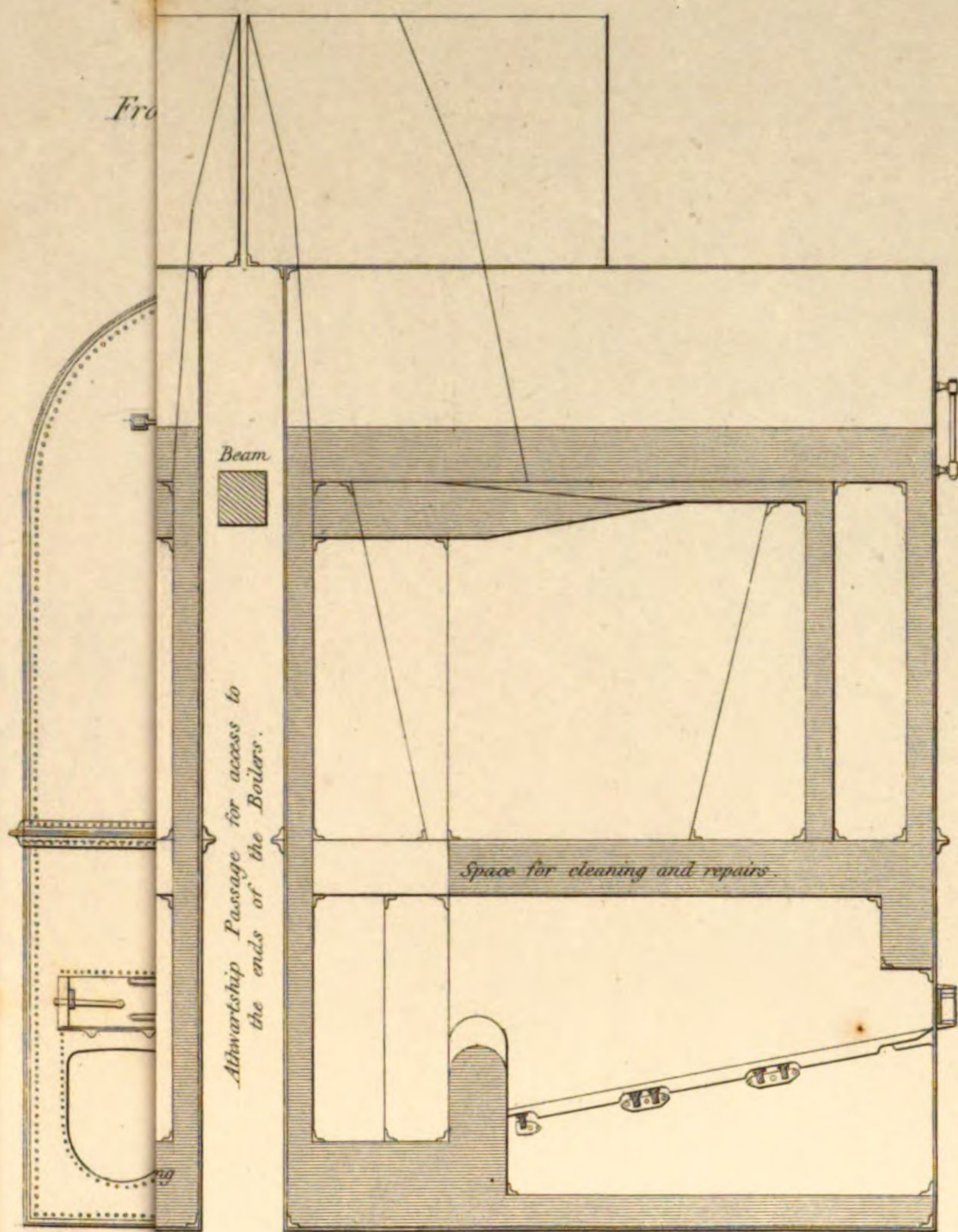
BOILERS OF THE "SINGAPORE"

470 HORSE POWER.

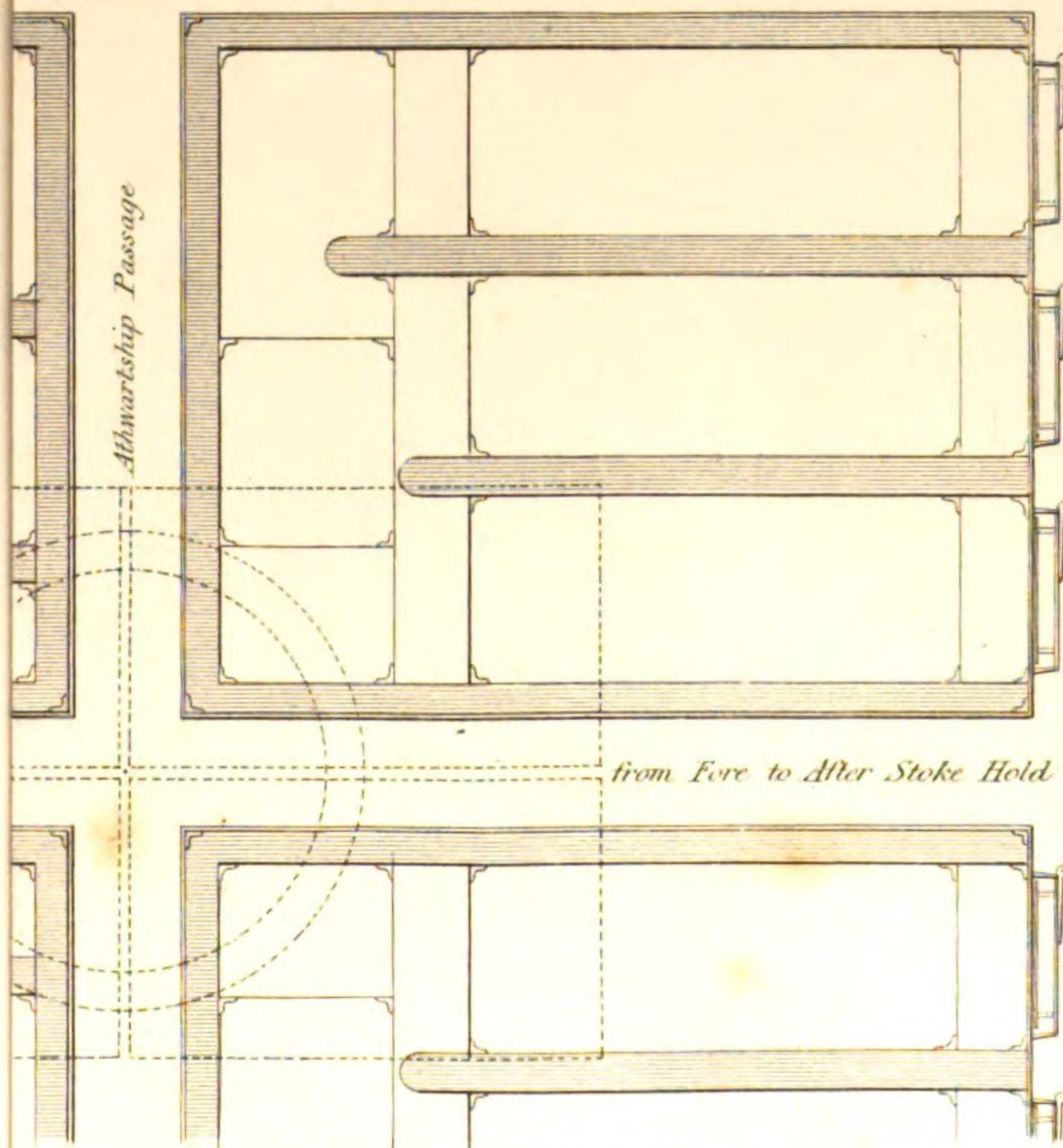
Peninsular and Oriental Company.

Scale $\frac{3}{16}$ inch = foot.

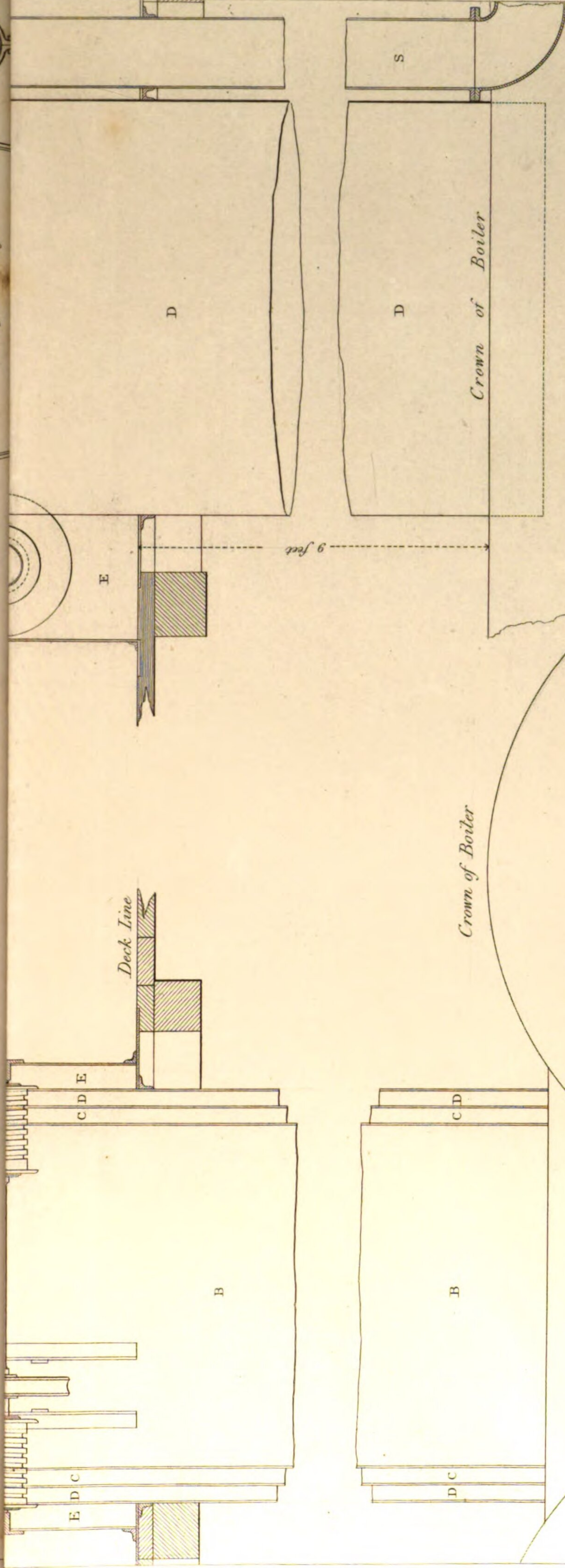
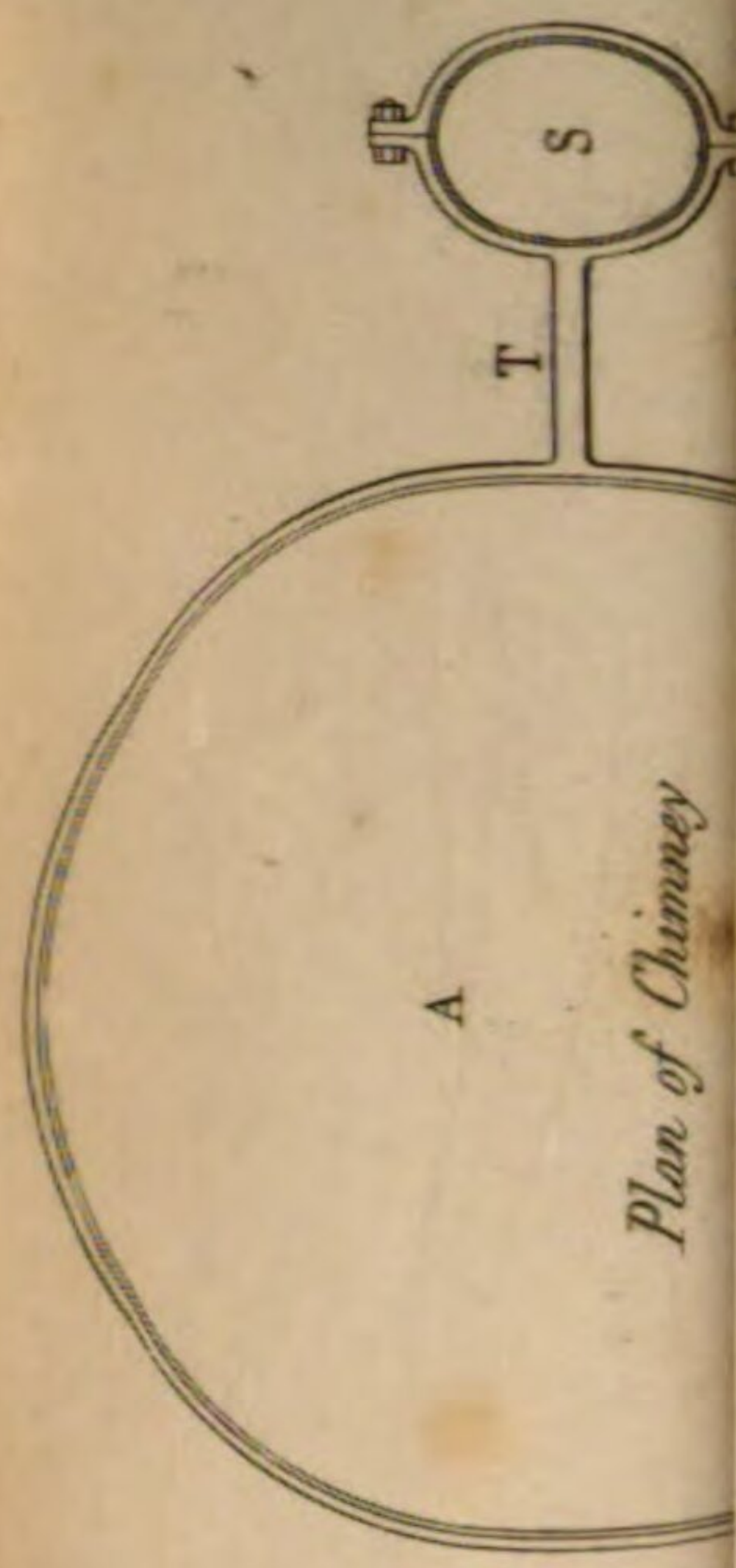
itudinal Section.



Plan

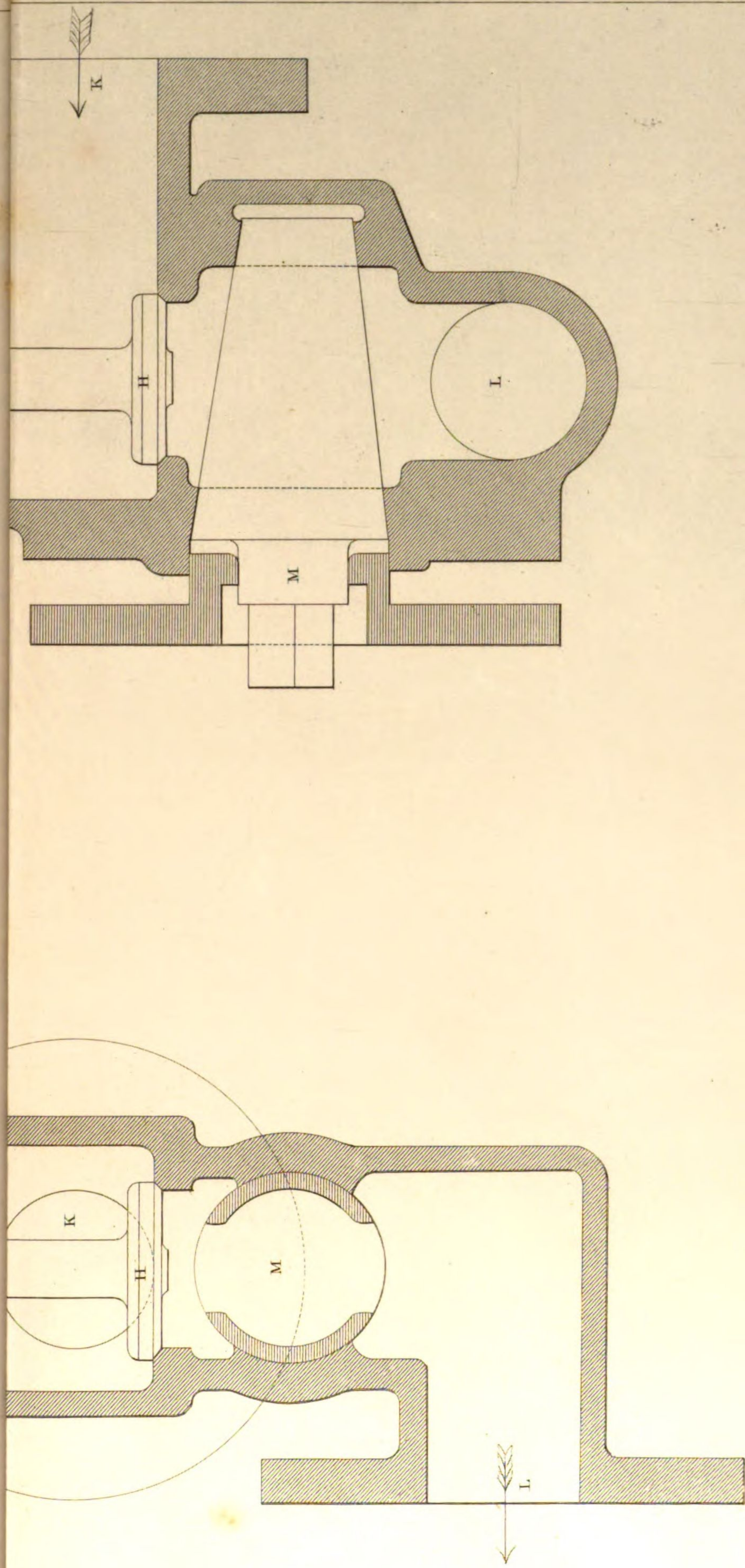


TELESCOPIC CHIMNEY OR SLIDING FUNNEL.
OF H.M.S. HYDRA.



MR DINNEN'S PAPER.

SEAWARD'S PATENT BRINE & FEED VALVES.

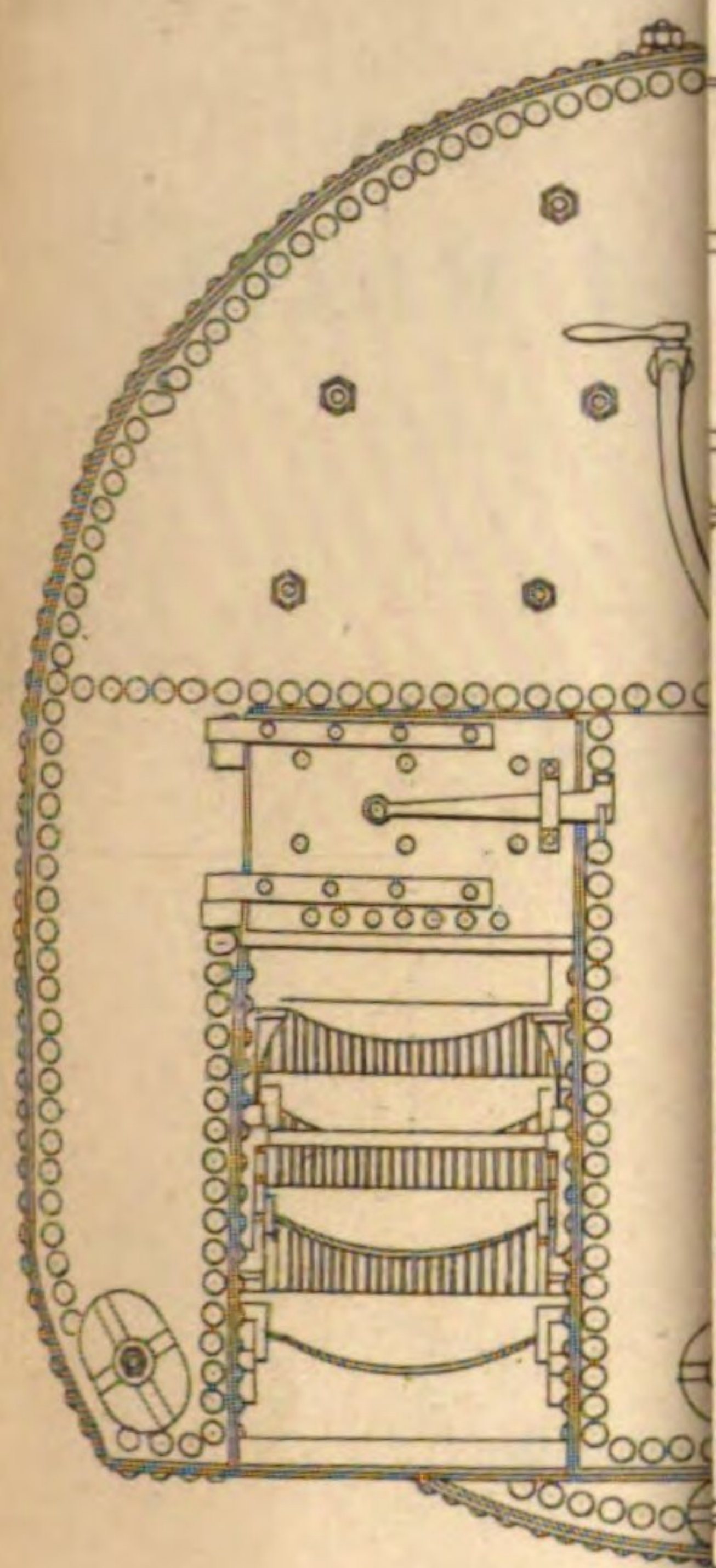


Seaward & Capel, del.

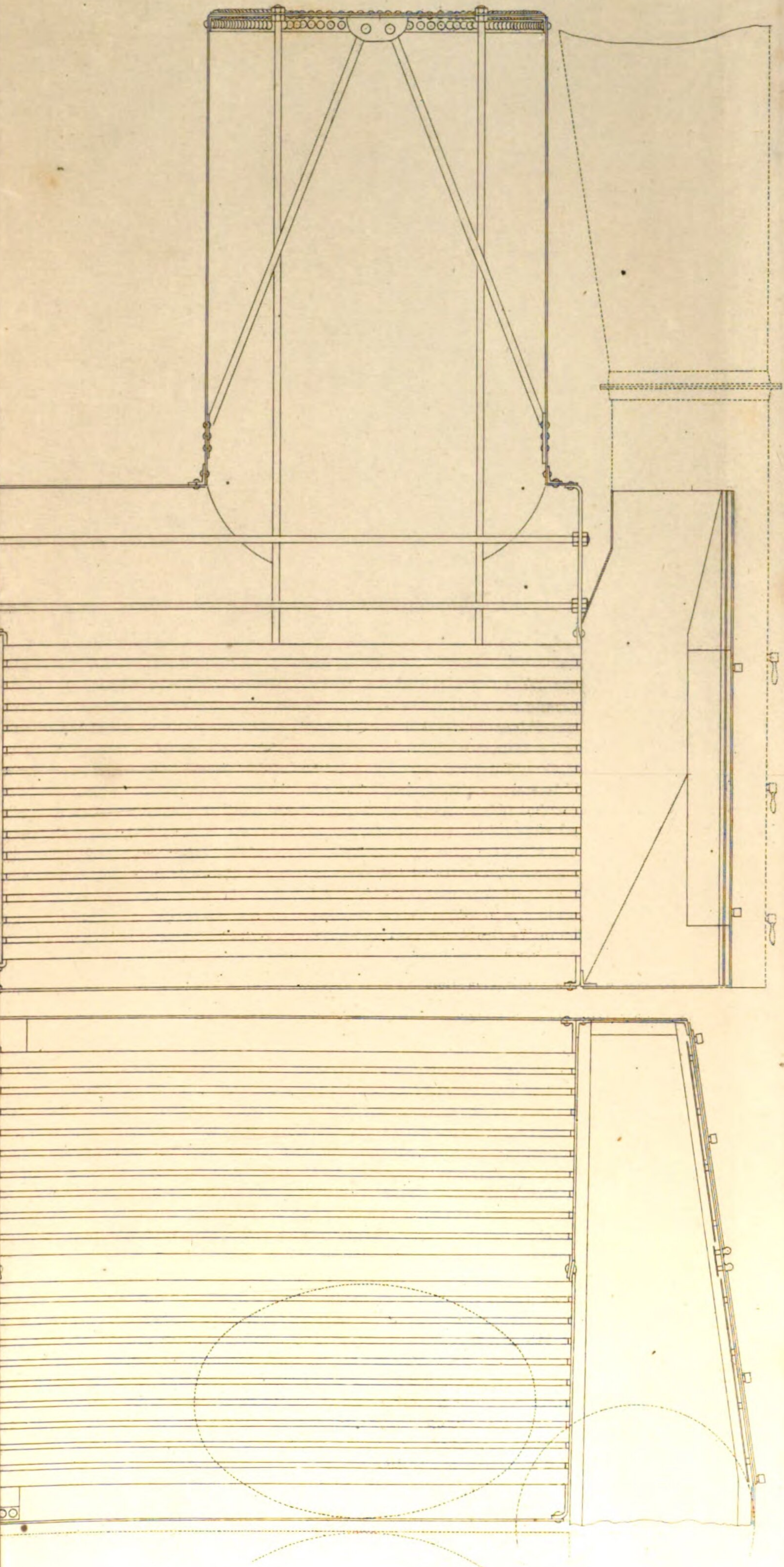
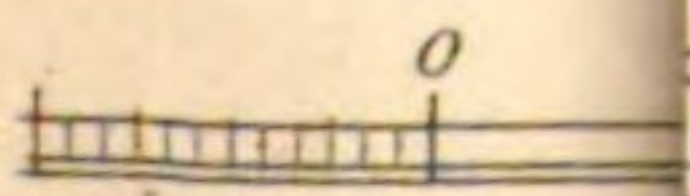
Published by John Weale, 59 High Holborn, 1852.

J.H. Le Roux sc.

Front
Elevation



BO



AN ESSAY
ON
STEAM BOILERS FOR MARINE ENGINES,

WITH
PRACTICAL EXAMPLES AND ILLUSTRATIONS.

BY JOHN DINNEN, R.N.

INSPECTOR OF STEAM MACHINERY IN HER MAJESTY'S NAVY.

TEN PLATES,

OF WHICH THE FOLLOWING IS A LIST.

Double-Story Boilers of Her Majesty's ship 'Devastation,' 400 horse-power.

Messrs. Maudslay and Field's Refrigerator Feed and Brine Pumps.

Brine and Feed Apparatus, as fitted on board the West India Royal Mail Company's vessels.

American Marine Boilers, designed and executed by C. W. Copeland, C.E., New York.

Boilers of Her Majesty's steam sloop 'Basilisk.'

Messrs. Lamb and Summers' Patent Boilers, as fitted on board the 'Singapore,' 470 horse-power.

Original Double-Story Boilers of the 'Great Western.'

Telescope Chimney or Sliding Funnel of Her Majesty's ship 'Hydra,' 220 horse-power.

Seaward's Patent Brine and Feed Valves.

Boilers of Her Majesty's mail packet 'Undine.'

[The Binder is requested to cancel this leaf when binding the complete volume.]

ON MARINE BOILERS.

BY J. DINNEN, ESQ.,

INSPECTOR OF STEAM MACHINERY IN HER MAJESTY'S NAVY.

WITH NOTES BY ROBERT ARMSTRONG, C.E.

1. THE paucity of information connected with steam navigation,—a subject, it must be allowed, of great national importance, and which has assumed a prominent feature in Her Majesty's Naval Service,—suggested the investigations from which the following practical essay on marine boilers has resulted. The incrustated state of the boilers of all steam vessels returning from the Mediterranean with mails, in the early stage of their employment, was calculated to impress the observer with the impracticability of making such voyages without producing like effects; no experiment having been made, or correct data furnished, at that period, to counteract the notion, so universally entertained, that the water of the Mediterranean holds more marine deposit in solution than that of the Channel.¹ It is probable that Dr. Halley's experiments on the evaporation of water from the surface of the sea assisted materially in the formation of this general opinion.

¹ The erroneous opinion respecting the greater saltness of the Mediterranean, notwithstanding this emphatic authority to the contrary, unfortunately still prevails to some extent among certain portions of the commercial community, who in a great measure compose or influence the directories of Steam Navigation Companies. After fourteen years of extensive popularity of Mr. Dinnen's Paper, both at home and abroad, it is surprising that this should still be the case, and can only be accounted for by the tendency to rest satisfied with being only half-informed on facts having a plausible theory to support them, however fallacious that may ultimately be proved to be. Foreign Steam Navigation Companies are perhaps most imbued with this notion, which cannot be too soon dispelled, as there can be little doubt that it operates prejudicially against the adoption of improvements in marine boilers having the least complexity of construction; for on proposing any improvements involving a departure

It is calculated that the Mediterranean evaporates no less than 5,280,000,000 tons daily: and this quantity far exceeds that evaporated from any other surface of equal extent, being entirely encircled by land; but it does not follow from this that the water is salter. Whoever has been in the Mediterranean is aware that the dews there are exceedingly heavy, and that they begin to descend some time before the sun has set: in still evenings indeed the dew descends where it has arisen, and no doubt much is precipitated on the land; but it must be borne in mind that land gives forth exhalations at all temperatures, as well as the sea. Again, the visible current always runs into the Mediterranean, in addition to the great rivers Nile, Danube, Rhone, &c., to supply that portion of water which the land may carry off. Experiments do not show the specific gravity to exceed that of other waters; and hence the general opinion alluded to must have been conjectural, and not founded on the result of investigation.

2. It cannot be too generally known that the thermometer is a good practical test of the concentration of a boiling solution of salt; of which the following is offered in illustration. Some years since, experiments were tried by Messrs. Maudslay and Field, and an apparatus adapted to marine boilers, the purpose of which was, that the water of the boilers should at all times be maintained at the same temperature and at the same degree of concentration; and I am not aware of any experiments for such an object prior to these.¹ It resulted from their investigations

from the ordinary routine form, we have been constantly met with this stereotyped 'saltiness of the Mediterranean,'—a similar impediment to progress on the ocean to that created on land by the once prevalent error respecting the slipping of the wheels of a locomotive on smooth rails.

According to Dr. Ure, deep sea water, from whatever locality, contains on an average in 1000 parts (by weight) nearly as follows:

- 25 of chloride of sodium (muriate of soda or common salt).
- 5.3 sulphate of magnesia.
- 3.5 chloride of magnesium.
- .2 carbonate of lime and magnesia.
- .1 sulphate of lime.

34.1

¹ It was in 1824-5, that Messrs. Maudslay and Field obtained their patent for pumping out of the boiler a certain definite proportion of the hot salt brine at each stroke of the engine, while at the same time its place was supplied by an equal quantity of feed water in its ordinary or less concentrated state, and at a lower temperature; an arrangement which, but for the important experiments detailed in the text by Mr. Dinnen, could not possibly have any practical value beyond what is called the 'constant blow off.' The *brine-pump* was therefore not generally adopted.

Shortly after the above period, the late Dr. Clanny, of Sunderland, the then well-known originator and improver of the safety-lamp, in conjunction with Mr. Scott, the eminent potter, together with the writer of these notes, were engaged in a series of experiments on the same subject, employing for that

that sea water boiling under a pressure of $2\frac{1}{2}$ lbs. on the square inch (the usual low-pressure standard) will arrive at 226° Fahrenheit in 24 hours, at 230° in 48 hours, and 232° in 60 hours, &c. ; at which period it will contain $\frac{1}{3}\frac{1}{2}$ of its bulk of salt. At 232° saturation takes place, and salt (muriate of soda) will be crystallized and deposited ; the concentration having progressed from 222° , the temperature exhibited at the commencement of the experiment. The boilers of course receive only the necessary supply of water for evaporation ; in the above instance 16 gallons per minute. These experiments I have frequently repeated under varied circumstances with corresponding results.

Sea water containing $\frac{1}{3}\frac{1}{2}$ of its bulk of salt, and the quantity evaporated being entirely fresh or distilled water, it is evident that all the salt injected remains in the boilers : the specific gravity of the water is thus constantly increased, and the salt, now more tenacious of its water of solution, requires an increase of heat to separate it ; so that with an uniform heat evaporation would proceed proportionally slower ; but the necessities of the engines requiring that it should proceed at all times equably, the fires must be urged accordingly. The temperature thus increasing (under the same pressure) with the saturation, a thermometer becomes a practical register of the density of the water ; of the waste of fuel, to a certain extent ; and a certain index of the danger to which the furnaces are exposed.

purpose the engine boilers at Mr. Scott's works, situated near the mouth of the river Wear, where the salt, mud, and other sediment accumulated at such a fearful rate, that out of four boilers supplying two high-pressure steam engines, one at least was always under repair or being cleaned out. The result of these experiments was the adoption of the plan of placing one or more small *collecting vessels* within each boiler, and then, instead of blowing the sedimentary deposits out from the general mass of the water in the boiler, the blow-off pipe was attached to the inner vessel, which stood at some little distance from the boiler bottom. This blow-off pipe being discharged several times a day, was found to be quite effectual in freeing the water of the boilers from nearly all its previous impurities.

The unlooked-for and at that time singular fact, first noticed by Dr. Clanny during those experiments which it is the purport of this note to mention, as it has not yet been fully followed up in all its important consequences to steam navigation, is, that in using salt water in steam boilers, the brine drawn from the inner collecting vessels is always in a much more concentrated state than the surrounding mass of water : so much is this the case in fact, that I have frequently found it to be a nearly fully saturated solution which crystallized immediately after exposure to the atmosphere, while the remainder of the water in the boiler was in the ordinary working state, that is, having only two or three times the saltiness of sea water, thus proving the possibility of drawing off *very salt*, and *comparatively* fresh water, from a boiler at the same time.

Similar experiments were made by means of apparatus attached to the boilers of sea-going steam vessels at Sunderland, Hull, and Liverpool, previous to 1830, some account of which is given in my 'Essay on the Boilers of Steam Engines,' 1838.

See additional note, A. See also page 175 of Division B of this work.

3. A particular arrangement was adopted in the above experiments: a thermometer was applied to the front of the boilers, ranging from 210° to 250° or 300° Fahrenheit, the bulb of which was immersed in mercury, contained in an iron box, protruding into the water of the boilers through the front thereof, so as invariably to partake of the same temperature; and so that its state could always be known by inspection. To apply the thermometer to boilers generally, it would be necessary to graduate it to suit the particular pressure on the safety-valve, the boiling point varying accordingly. An objection may be offered, that the thermometers thus applied are very liable to get out of order. To prevent errors of this kind, a common Fahrenheit's thermometer may be employed without reference to the pressure on the safety-valve, by immersion in water drawn from the boilers at regular intervals, and boiling under the pressure of the atmosphere; which, if possible, should be noted when nice observations are required.

Now, as muriate of soda is an exception to the general law of the solution of salts in water,—as scarcely any more is taken up at a boiling heat than at a moderate temperature,¹—it is clear that this boiling in the air exhibits the exact state of the brine, whether from a high or a low pressure boiler; the thermometer alike showing its specific gravity, and of course acting sufficiently for this purpose as a hydrometer. In this way the experiments referred to in this Paper have been made.

4. An essential part of the apparatus alluded to for equalizing the concentration of salt in the boilers was a pump, technically called a brine-pump, the particular office of which was to extract from the lowest part of the boilers, at each stroke, a certain aliquot part of the water supplied by the feed-pump. One-fifth of the quan-

¹ According to Gay-Lussac, quoted by Dr. Ure in his 'Dictionary of Arts and Manufactures,' 100 parts of water dissolve

35.81 parts of the salt at 57° Fahr.

35.88 " " $62\frac{1}{2}$

37.14 " " 140

40.38 " " $229\frac{1}{2}$

thus making the difference above alluded to less than 5 per cent. It is also observed by Dr. Ure, that the salt, although obtained from the waters of the ocean, is never perfectly pure; but he adds, "the more heterogeneous the salt, the more soluble it is, by the reciprocal affinity of its different saline constituents." This observation may serve to throw some light on the use of sundry specifics recommended by various patentees for preventing deposition of salts of lime in land boilers,—some of them prescribing the use of large quantities of *common salt* for that purpose. It may also serve perhaps to explain what has sometimes been stated as a strange discrepancy, that the more frequently some marine boilers have been blown out at sea, the harder and more compact was the scale of sulphate of lime always found remaining.

For Dr. John Murray's 'Analysis of Sea Water,' see page 36 of Division B, and at page 37 will be found Mr. Watt's experiments.

tity injected was found to be that necessary to be withdrawn, four-fifths being the amount required to be evaporated for the supply of the engines. It having been before observed that the water evaporated is fresh or distilled water, that remaining being specifically heavier than sea water in proportion to the quantity evaporated, it is evident that without a change the saturation would increase till the boiler became a common salt-pan. The operation of the brine-pump, however, maintained the water uniformly at about 226° , at $2\frac{1}{2}$ lbs. pressure per square inch; at which temperature it contained $\frac{5}{32}$ of its bulk of salt: hence, as much salt was extracted by the pump, in a gallon of brine, at $\frac{5}{32}$ concentration, as was injected by the feed-pump in 5 gallons of sea water containing $\frac{1}{32}$ salt: thus maintaining the condition required, which being within the prescribed limits of saturation, viz. 232° , sulphate of lime only could be deposited; but at this period the deposition of muriate of soda was the evil sought to be averted, and this arrangement did it effectually. The lime remains to be considered, of which more hereafter.¹ The brine-pump has given place to the

¹ Mr. Robert Murray, in his recent 'Rudimentary Treatise on the Marine Engine, &c.,' says, "if we would preserve the water of the boiler at a degree of saturation, indicated by $\frac{2}{32}$ of salt, we must blow off *one-half of the feed water*; if at $\frac{3}{32}$, then *one-third* must be blown off; at $\frac{4}{32}$, *one-fourth*, and so on;" but that it should never be permitted to exceed $\frac{3}{32}$: in other words, to prevent a boiler "salting up," it is necessary to blow off as much hot salt water from the boiler continually as is equal to from one-third to one-half of the whole quantity of water required to feed the boiler;—thus substantially agreeing with Mr. Dinnen, and with facts which exhibit, in a sufficiently strong light, one of the natural inherent difficulties that beset the subject of marine boilers. This difficulty evidently involves an additional expenditure of nearly 50 per cent. to all that portion of the fuel used in raising the temperature of the feed water to that of the steam, which in a general way, for condensing engines, may be taken as rather less than $\frac{1}{12}$ or about 8 per cent. of the whole fuel used. On this subject see Mr. Tredgold's note to art. 510, page 293, Division B, where he infers from Dr. Faraday's experiments, that $\frac{1}{14}$ part only, or about 7 per cent. of the effect of the fuel, need to be lost by a similar arrangement.

How far the immense expenditure of ingenuity in improving the brine or 'change-water' pump, as it is now called, together with the invention of the 'refrigerator,' is justifiable, in order to save some portion of this 8 per cent. of fuel, is a question worth examining, and of no small importance to the progressive improvement of the marine boiler. Granting that a moiety of this 8 per cent. of waste heat may be saved by such means, we may question the wisdom of directing the energies of our marine engineers to such small savings, while larger ones lie before them unlooked at. One of the main necessities entailed on us by this compulsory wasting of nearly half the contents of the boilers, which has been thus unaccountably overlooked, is, that in order to make up for this deficiency we ought to add nearly 50 per cent. to their evaporative power; meaning, of course, not merely increase in their heating surface, but in their general dimensions, fire-grate surface, and steam and water room, especially the latter. In short, seeing that the breadth of fire-grate surface is limited by the width of the ship, and supposing that one-half of the decrease of efficiency arising from blowing out is met by a judicious adaptation of change-water pumps and refrigerators, our advice is, that marine boilers ought to be generally increased in length about 25 per cent., a change which need not necessarily involve an increase of weight to anything like the same extent; while the advantages derivable from boilers of extra capacity for a given nominal power of engines are manifold and well known.

See additional note, B.

indefinite operation of blowing out ; but, from my knowledge of its advantages at sea, I should recommend its use in all *land* engines where fresh water cannot be obtained ; an opportunity being afforded of recovering nearly all the heat abstracted from the boilers with the water thus withdrawn.

5. The incrustated state of the boilers, to which I have referred, appeared at variance with observations made by me in the North Sea, the Channel, &c., on the influence of sea water on the interior of marine boilers. To determine the fact, I carefully noted the degree of saturation of the water of the boilers at various periods each day, as indicated by Fahrenheit's thermometer immersed in a portion drawn therefrom, and boiling under the pressure of the atmosphere, on my first voyage, in 1831, from Falmouth to the Mediterranean and back ; the result of which was, that having blown out a portion of water from the boilers (which were of copper) every two hours during the passage, they were on each successive examination found perfectly clean and free from marine deposit, with the exception of a slight film ; the thermometer being at 215° , and not having varied in excess throughout the voyage. This circumstance was without precedent ; no mud-plate having been removed, or men employed in the boilers during the voyage.

From extensive experiments of Dr. Davy, (brother to Sir Humphrey,) to ascertain the relative saltness of the sea in various situations, its specific gravity was found to vary very little, except when influenced by the influx of large rivers ; and this conclusion is corroborated by other scientific men with whom I have conversed on the subject, in the Mediterranean.

From the coincidence of the above experiments, therefore, it may be inferred that the water of the Mediterranean is not, in its effect, salter than that of the Bay of Biscay or the Channel,—that boilers hitherto incrustated must have contained a solution saturated to a much higher degree than that exhibited in the case alluded to,—and that marine boilers are not more subject to incrustation during a voyage to the Mediterranean, than on any other voyage of similar duration. Also from recent examinations of boilers returned from the West Indies, and the reports from the 'Atalanta' and 'Berenice' steam ships sent out by the East India Company, I am led to the same conclusion as regards the waters of the Tropics.

6. The specific gravity of the water of the boilers, as indicated by the thermometer remaining uniformly at 215° , and its not having indicated a higher degree of concentration on either passage, the delay of blowing completely out on the voyage became unnecessary, and this was justified on each arrival ; hence no time was thus wastefully consumed. The order for laying-to every three or four days, to blow the boilers entirely out, at sea, is still in force in the Navy, and forms part of the instructions to Officers commanding Her Majesty's steam vessels ; but how far this is necessary, the fact of having never blown off entirely at sea will explain : I believe

the practice is now rarely resorted to, although some are still inclined to think it necessary.

7. I am also decidedly of opinion, that it is unnecessary to prescribe any specifics for the prevention of deposit or chemical action in copper boilers affixed to marine engines, such as the introduction of large masses of iron, &c.; the same effects exhibiting themselves in iron as well as copper boilers, when submitted to the influence of a highly concentrated solution of saline matter, &c. in a constantly boiling state,—viz. deposition of the salts, &c., and ultimate destruction of the boilers. As a proof of the fallacy of such applications, the incision I made in a copper boiler with a chisel was not obliterated or sensibly diminished by the action of the water alone, at the end of three years; the boilers, during the time, being employed in the North Sea and Channel, and free from incrustation, except a film with which the tubes were whitened. After the experiments before alluded to, the boilers were constantly employed in the Mediterranean and on the Lisbon service, and were not in any way submitted to the form of cleaning out till the expiration of the third year; a very slight scale was then removed, leaving the surfaces scaled, precisely as when rolled.

8. The remarkable preserving influence these calcareous matters possess over copper and other metals has been exhibited in the bronze guns, raised by the enterprising Mr. Deane, from the 'Royal George' at Spithead; which properties, if generally known, might be available for some useful purpose. I give the notice extracted from the 'Mechanic's Magazine':—"The guns are incrustated with a coat of lime about the twentieth of an inch thick, to which several oysters have attached themselves; but these, as well as the calcareous coating, separate very easily from the metal, leaving the gun perfectly clean and sharp in its castings." It observes also, "that the rings of wrought iron attached to the breech were totally decayed, the cast-iron shots and wads being in a perfect state of preservation." The preservation of the shot is easily accounted for, being pent up by its wad; but the galvanic agency of the iron, exposed to the water, neutralized its destructive effects on the gun; and hence the calcareous formation, which, when the existence of the iron should totally cease, would certainly defend the bronze from all attacks of the sea. The adhesion of oysters favours this view of the circumstance.

Since noting the above in the Mediterranean, I have seen in the Arsenal at Woolwich several of the guns alluded to, which in every respect confirm what is stated in the extract. The condition of these guns is a fair specimen of the interior of a boiler after a few voyages to sea, except that in the case of the boiler the surfaces are incrustated more uniformly: the coating, however, in both instances equally protects the surfaces from the destructive attacks of the sea water; but the causes of deposition are different: in one case it is effected by galvanic influence; in the

other by depriving the water of a component part, by the simple operation of boiling.

9. The experiments of Davy on copper sheathing induced many to attempt the application of the principle to other purposes, and marine boilers (copper) proved to be a *failure* of this description; for the electric action which was induced by the application of cast iron, zinc, &c., to copper sheathing, favoured marine vegetation, and the adhesion of shell-fish, lime, &c., to the ship's bottom; a disadvantage greater than the evil it was intended to obviate. Iron placed in a copper boiler, for the object alluded to, was speedily decayed, without apparent effect: in fact, it was treating the boilers for a distemper which existed only in imagination. Hence no calculable diminution of weight is sustained in copper boilers from the action of salts, &c., when held in solution, at sea: but when the interior becomes incrustated with a lamina of insoluble calcareous matter, which firmly adheres to the surfaces of the flues and fire-places, and thus certainly protects them from chemical action, and frequently fills the interstices or water-ways of the boilers, it requires violent mechanical means to extract it. In removing these masses of scale, the boilers are much injured; quantities of rivet-heads imbedded in the deposit, and portions of the metal, being alike separated by the instruments used for the purpose. These facts obtain alike in iron and copper boilers.

10. An evil, however, most sedulously to be avoided, is the accumulation of soot, salt, &c., in the flues; the chemical action of which is very destructive to boilers. Water, whether cold or boiling, filters through numerous apertures insignificant in dimensions, and almost inseparable from the intricacy of the construction, and mixes with the soot, forming a combination which corrodes the material very rapidly. The heat of the boilers, when employed, evaporates the water, and leaves the salt, &c., in a concrete state; which, when cold, is again dissolved, and recommences its action more formidably.

On a voyage to the Mediterranean in the months of September and October, 1835, the stay at Malta, on the passage to Corfú, being too short to clean out the flues or to inspect the interior of the boilers, these duties were necessarily delayed till the arrival at Corfú out, and thence to Gibraltar home; and in both instances there appeared an unusual quantity of soot, &c., in the flues. The congeries of salt, soot, and water, was thrown out upon the iron plates of the engine-room flooring, where in both instances it remained for nearly two days (the time occupied in properly sweeping); when removed and the plates well washed, a pretty and novel phenomenon was exhibited. The iron plates had precipitated the copper from the solution which covered them, exhibiting a permanent metallic surface of copper. This is a valuable practical corroborative of the observation just made concerning the great transmission of the metal, when such solvents are not removed

at frequent intervals. I was first attracted to the fact at the above period, have had many opportunities of seeing it repeated since, and have collected the water, to amuse others by the experiment of the precipitation of copper by iron, from an acid having a greater affinity for the latter.

The leaks whence the salt resulted, on careful examination, were found so unimportant, that the usual measures to stanch them could not be attempted without the risk of increasing the evil; particularly as this voyage immediately succeeded a general caulking of the flues in parts requiring it, when numbers of screwed rivets were substituted for defective ones.

11. Now, as the defects exist exclusively in the angle pieces and rivets of the bottom of the flues, the top and sides being invariably tight, I have applied a fillet of Parker's or Roman cement in these cases, so as to completely enclose the angle pieces, with their defects, and have thus succeeded in checking the destructive effects of these otherwise trivial, but numerous and incorrigible channels. I have recommended its adoption in other steam vessels, with equal success and satisfaction; and from some years' experience of its advantages, when applied to the cleaned surfaces of the defective parts, I suggest its use under similar circumstances in iron boilers; although inconveniences here alluded to are less frequent and more easily checked in these boilers by the usual method of chincing, &c. It must be understood that I here confine myself entirely to cases where mechanical skill is found to be ineffectual; the cement need be resorted to only when every other means has failed.¹

I also conceive that copper boilers experience more deterioration than iron from these deposits; the bottom flue-plates of a copper boiler, upwards of $\frac{3}{8}$ of an inch in thickness, (where water was present, as before described,) being totally decayed in twelve months; the side of the plate exposed to the action of the salt water alone being unimpaired;—a fact which I never witnessed in an iron boiler under similar circumstances. Hence the rapid decay of boilers if these deposits are allowed to remain in the flues an unwarrantable space of time. The only mode, of course, to obviate this, is to sweep the flues as often as convenient; and the boilers, it should be provided, are to be kept perfectly dry when not employed.

12. To keep those parts of the boilers clean which are exposed to the influence of the boiling salt water, it appears to be absolutely necessary to hold the salts in solution, since deposits are separated from the water some considerable time before salt

¹ Instead of Roman cement, which is liable to crack and come off, we have in our experience found Scott's anti-corrosive cement to be preferable for this purpose. It is a mixture of calcareous and siliceous ingredients combined with oxide of lead in such proportions as enables it to expand and contract nearly in the same ratio as the iron, to which, in consequence, it adheres with great tenacity. On the deterioration of copper boilers by corrosion, see foot-note to art. 23, page 21.

is formed, and at a much lower temperature; 220° having been esteemed a limit (under the pressure of the atmosphere) at which a boiler begins to incrust, while my experiments have shown that 215° should be the maximum. Professor Faraday's experiments on sea water appear to confirm these observations: 1000 parts of sea water being evaporated, 825 parts of steam could be drawn off before any deposition commenced; but then the *sulphate of lime* was deposited; and proceeding till 110 parts remained, the common salt began to crystallize and deposit till $35\frac{1}{2}$ parts remained only; when the muriatic acid, from the decomposition of the muriate of magnesia, began to separate. About $\frac{8}{9}$ ths of the water may be raised in steam before the salt is deposited.

13. To obtain the required condition, I recommend that the practice of blowing out should be periodically and promptly attended to in the Channel as well as at sea, so as to effectually expel the earthy matters while agitated, and prevent induration. I also suggest the expediency of engineers strictly examining their boilers prior to a long voyage, in order to ascertain that their blow-out cocks and pipes are in perfect order. A due circulation of the water in the respective boilers should likewise be attended to, that the blowing out may equally influence the whole; and blow-out cocks especially should be so arranged and adjusted that their use may be quite practicable on all occasions at sea; as the due performance of the boilers, and consequently the certainty of a passage, materially depends on attention to these particulars.

14. The construction and arrangement of the blow-off cocks and pipes of most vessels in Her Majesty's Service were formerly very defective: in some instances, four or five men were summoned to attend when the boilers were blown off, in order to shut the cocks, which were often jammed by expansion; in other instances the boilers were blown off through the hand-pump, to obviate the risk of the cocks jamming. The boilers, in consequence, were insufficiently attended to; the construction not admitting these duties to be performed at all times with safety. Independently of these difficulties, the pipes through the ship's bottom were frequently of cast iron, and were often severely attacked by bilge-water between the cocks and the sea; and thus the safety of the vessel depended on the slightest tenure.

These remarks still apply to existing arrangements on board many vessels.

15. The safety-valve and pipe invented by Mr. John Kingston is so constructed that a conical valve, fitted in the pipe which is introduced through the bottom of the vessel, opens outwards to the sea, and is attached to a copper rod under the control of the engineer: thus, in case of any difficulty arising with the blow-out cocks, the valve can be immediately closed; and being entirely within the thickness of the ship's bottom, is always protected from accident; while in case the

pipe within the vessel were broken, the pressure of the sea would maintain the valve firmly in its place.

It is not generally known, except to those practically acquainted with engineering, that a steam vessel's bottom is perforated with many large holes, each equal to sink a ship in a very short space of time, particularly when it is understood that they are for the most part pierced close to the keel, where the pressure of water is greatest. It would give additional confidence to every one crossing the seas by steam, if all these holes were rendered as secure as the blow-out pipes now are by Kingston's safety-valve; and from the necessity of frequently examining and grinding the sea cocks, the adoption of valves would obviate the necessity of docking for these purposes alone, and is a strong inducement to their general employment in every steam vessel not confined to the limits of river navigation.

16. Instances are not rare of boilers being permanently injured, and sometimes totally ruined, in a first voyage, whether iron or copper; occasioned alone by neglect of proper precautions. Incrustation, which is certain, strongly opposes the efforts of the men to generate steam, the combustible portion of the fuel being consumed in heating the plates of the boiler; and the heat must necessarily pass through strata of *stone*, (if I may be allowed the comparison,)—a very bad conductor of heat,¹—before it is given out to the water; which being highly saturated, requires an additional, instead of a diminished, supply of caloric, to separate its aqueous and volatile portions from those that are fixed, which are constantly subsiding on the tubes. It requires no argument to show that the fire-places and flues thus subjected to intense heat become nearly red-hot, and consequently expand much beyond their usual limits; while the stay-bolts and other ties, holding them with immense force, either break or cause the plates to crack in the weakest place, which is generally in the wake of the stays, joints, or bends,—parts, of course, the most heated from the increase of mass; sometimes even the tubes collapse, the powers of expansion resisting all opposition.

Serious delays and many inconveniences arise from the evils here described, since in most cases immediate repair is absolutely necessary, and can only be effected at the expense of great physical exertion. In fact, from observations on sea water, and its effects on marine boilers, for many years, I am convinced that it is absurd to expect to make a voyage with success if blow-out pipes are choked or

¹ This is remarkably the case with the carbonate of lime, which, in fact, *is stone*. But we have found the crystallized deposits of the *sulphate* of lime to be in some measure an exception. Experiments indeed show that boiler scale so composed is not very much inferior in its conducting power to the iron itself. The increase of thickness, however, though this should be the case, is an evil sufficiently potent to render its removal or prevention desirable.

otherwise disordered; or even that at the end of three days, without a change of water, the boilers will not be incrustated to a considerable extent.

17. The injury sustained by some boilers, either from the above cause or from the neglect of blowing off uniformly at sea, has by some been erroneously attributed to the intensity of the draught, which they supposed to cause incrustation by burning the material. A tolerable draught appears, however, to be preferable, and not injurious to a boiler, being always under control;¹ moreover, I have invariably observed that boilers with insufficient draught expend more coals, with a considerable addition of labour, than others adapted to engines of equal power where the draught is capable of extracting the whole of the combustible matter of the coal, and vitrifying the residue; for a great waste attends the former, from the constant necessity of clearing the bars. I am also of opinion that no serious deposit can be formed if change of water is duly attended to and the evaporation constantly supplied; and that the sound plates will not experience injury if water alone is in immediate contact and the essentials of construction properly observed: for when the fires are in a state of active combustion, the iron or copper rapidly absorbs the

¹ Mr. Dinnen's preference for a 'tolerable' good draught is one of such decided coincidence with that of every intelligent practical engineer we have met with, and the reasons given are all so identical, that the question occurs, what is the measure of a tolerable good draught?—can we have too much of it, or has there ever been such a thing as an *intolerable* good draught in a steam boat? We confess to never having met with an instance of the latter kind, or with any one who has, provided it was "always under control" by dampers or otherwise. A really good chimney draught, either in a marine or land boiler, is perhaps as incommensurable as a stoker's conscience for a draught of another description; although we have heard some of those worthies venture on a *definition* of what they would call *too good* a draught,—namely, such an one as would "draw the coals into the furnace, and give them some trouble to draw the shovel back again." That there should be any strong draught, however, or any indraught at all, *at the time* the coal is being thrown into the furnace, is quite opposed to all correct principles in the art of firing.

The gauge or measure of draught is the force per square foot, or inch, with which the external atmosphere presses against the under-side of the fire-grate, or exerts in passing between the fire-bars or other similar openings to the inside of the furnace. It is most easily measured by means of a short column of water in a small inverted glass syphon, having one leg bent at right angles, and passed through a large cork, which may be conveniently held by the hand to any small aperture in the fire-door or in the brick-work of the fire-place or chimney. We have used this simple instrument many years as a convenient substitute for Dr. Wollaston's differential barometer. The difference in the heights of the columns of water in the two legs of the syphon is easily gauged, by means of a slip of card-paper, to less than the $\frac{1}{16}$ th of an inch, which is sufficiently near for all practical purposes. A furnace capable of burning away 8 or 10 lbs. of Newcastle coal on each square foot of an ordinary fire-grate per hour, will draw, in this gauge, from $\frac{1}{4}$ to $\frac{3}{8}$ inch of water; the same quantity of inferior coal requiring nearly $\frac{1}{2}$ inch, which in the manufacturing districts is usually called 'a good draught.' The best house-fire draught will seldom exceed $\frac{1}{4}$ of this, or $\frac{1}{8}$ inch of water.

caloric from the fuel, and as speedily transfers it to the water, which is accordingly in a greater or less state of ebullition, when not prevented by incrustation; the temperature of the plates then not very much exceeding that of the water.

18. In iron boilers it is difficult to insure the duration of the plates, for various reasons. Boiler plates are often on inspection apparently sound and of good quality; but when submitted to the heat of the furnaces, films of the metal opposed to the fire, where adhesion was not perfect, become separated in the form of blisters or cracks, (according to the nature and situation of the latent defects,) which are on examination frequently found to exist through the whole plate, to an extent often exceeding half its thickness.¹ On testing plates of various kinds for experiment, by heat,

¹ Every practical boiler-maker is of course well conversant with this fact, but it is one of so serious a character, as well as being perfectly irremediable by any known means, that it cannot perhaps be held up too frequently to the attention—not of engineers merely—but also to the proprietors of steam-works, in order to induce them never wantonly to sanction higher steam than is necessary under the often expressed fallacious notion that “it is quite as safe as low.” Although the reckless use of high-pressure steam in marine boilers or in river steam boats in this country has reached to nothing like the extent it is carried to in America, yet the days of high pressure and competition with that great power are evidently rapidly approaching; and as accidents *will happen* sometimes with the most careful management, even at the moderate pressure of 8 or 10 lbs., we are inclined to think it preferable to show how best we may use high pressure with the greatest safety and advantage, rather than keep up an unavailing contention against the prudence of using it at all. This conservative doctrine of what is called the “old school” of engineers we acknowledge to have assisted in upholding for many years past, though for a very different reason. There is, however, quite as much justification for the most bigoted adherent to Boulton and Watt’s limitation of $2\frac{1}{2}$ lbs. per square inch instead of 8 or 10 lbs., now the universal practice in low-pressure engines, as there would be in preventing the modern engineer advancing from 30 lbs., the ordinary standard for high-pressure non-condensing engines, up to 100 or 120 lbs., which last or any pressure above 100 lbs. per square inch may very properly as a distinction be called *extreme* high pressure.

Respecting the great difficulty, if not impossibility, of detecting all those original defects in the make of wrought-iron boiler plates called ‘flaws,’—incipient blisters, in fact,—we have some recent evidence in the case of an explosion of the boiler of a steam boat called the ‘Eastern City,’ this summer (1852), in New York, by which five persons were killed while getting up steam for her trial trip.

It was a *new* boiler, made at the Allaire Works, of the very best Pennsylvania iron, and of a size and form capable of standing 36 lbs. pressure to the square inch, yet the explosion took place *when there was only 14 lbs. pressure*. The ‘Scientific American’ New York paper, from which we take these particulars, states “that the accident was a very unexpected one; *it was not caused by any carelessness*, and no one could have anticipated the sad result,” and gives the testimony of some witnesses before the coroner’s jury, which is very important. One of them, Peter M’Millin, one of the superintending engineers of the Allaire Works, stated that he was “fully acquainted, *so far as possible, by observation*, with the material in the boiler in question, as well as with the material used in all other boilers built at the Allaire Works;” he was present at the time of the explosion, and corroborated the testimony of Thomas Fitzgerald and others that the accident was caused by a flaw in the iron “which could not have been detected while the boiler was making.” The boiler was made in the usual manner, and the iron was $\frac{3}{8}$ ths of an inch in

punching, breaking, &c., those of the most perfect exterior were often found to be much laminated; and those parts of boilers which have been previously heated and bent to form the bridges, and on which (when constructed) the fire incessantly impinges, will, if defective, most readily afford opportunity of detection. I have known boilers to run for some months on occasional service in the Channel during the existence of defects which did not exhibit themselves till the plates were overheated; no doubt, through partial incrustation, experienced on a voyage to the Mediterranean, immediately succeeding.

19. Instances seldom occur of copper plates cracking, unless from causes already described; a material difference existing between the manufacture of copper and iron plate, which renders it incompatible that they should display similar effects from the cause of heat alone. The former, after certain refining processes, is cast in open iron vessels, forming convenient cakes, and of course solid and free from air and extraneous matters, prior to being heated and rolled; while the latter, in masses prepared from scraps, or slaps, is raised to a welding heat, with its heterogeneous accompaniments, and then submitted to pressure under the rolls; on the judicious observance of which processes a perfect union of the parts and consequent solidity mainly depends.

thickness. The editor of the above-mentioned paper very properly asks, "If this boiler caused so much damage to life, and burst with only 14 lbs. pressure, is it not reasonable to conclude that many explosions must take place when steam is carried as high as 50 or 100 lbs., although the boilers may be constructed to stand double that amount of pressure?" Not a doubt of it; and we could adduce abundant evidence in this country to substantiate this affirmative, so much so, as even to induce the belief that very few explosions indeed have arisen from carelessness, and still fewer from 'sticking' or reckless overloading of safety-valves, &c., &c., so very commonly ascribed, but which we have long looked on as vulgar errors, greatly detrimental to the improvement so much needed in this part of the apparatus of steam boilers.

Testing boilers by hydraulic pressure after they are made, so much insisted on by our U. S. friends, and for which a Bill now before Congress against the explosion of steam boilers especially provides, does not always insure safety. We know of an instance in London, within the last few months, where a tubular boiler made of half-inch plates, double riveted, and quite new, calculated to work at the extreme high pressure of 150 lbs., intended to be proved at 300 lbs., and was actually tested up to 130 lbs. by hydraulic pressure; yet on a subsequent application of the same test was burst by a pressure of 70 lbs. per square inch,—a piece of a defective plate, *weakened*, as I think, by a double seam of rivets, flying out of the side of the boiler with violence: accidental circumstances alone determined this bursting test being water instead of steam, otherwise extensively fatal consequences would have ensued.

For the best method of guarding against explosion from collapse of flue in high-pressure boilers, see Note to page 276, Division B. Also see additional Note, C.

ADDITIONAL OBSERVATIONS AND GENERAL REMARKS.

20. Enough has been stated to show that muriate of soda is crystallized subsequently to the deposition of the sulphate of lime ; and from further observations, I conclude that the sulphate of lime *will* deposit and indurate at any temperature from 212° upwards, and at any degree of concentration ; the more limited this is, of course the less deposit ; so that a person having the care of marine engines on a station cannot be too much on the alert to meet the various mechanical difficulties which may interfere with *prescribed* arrangements for the good conduct of the boilers ; which arrangements are not always disposed so as to effect the desired purpose, particularly when boilers are composed of many parts. Engineers do not give that attention, at all times, to the due circulation of the water in the respective boilers which their necessities require : not unfrequently I have known three or more boilers communicating freely above the furnaces, and by *side* pipes beneath : the pipes often become choked ; consequently in blowing off the front boiler, the water equally descends in the whole, the after-boilers yielding their quota from the surface, (where they communicate freely,) while the earthy matters, and common salt even, are permitted to subside in receptacles whence they cannot be removed.

If there were even three or more cocks in such case, it would not be possible, day and night, nor would it be safe, to open all at the same time ; and if one boiler is blown off at the end of two hours, as recommended, each boiler remains six hours before the operation is repeated. The descent of the water should be equal and simultaneous from all the joining boilers, if possible ; which, if not effected, will often permit one boiler to be perfectly clean, whilst its neighbour is thickly incrustated. Many examples of the neglect of *proper* arrangements for circulation of the water in the respective boilers, and of injury thereby sustained, have induced me rather to enlarge on this matter ; but still I fear that nothing but the use of *distilled water* will ever thoroughly obviate the evils to which marine boilers are subject on very long voyages, although at the end of five or six years in active employ a copper boiler may not be liable to injury if properly attended to ; while it is notorious that the fire-places of iron boilers of similar construction, employed between Falmouth and Corfú, require repair, almost invariably, at the conclusion of every voyage.¹ I believe that four voyages to the Straits are the most that have been made prior to a general repair of the boilers.

¹ In mentioning the 'use of distilled water' as one of the only possible alternatives, besides *copper* boilers, to the ruinous and expensive system at that time carried on by the Admiralty, when, as Mr. Dinnen

I have stated that the 'African' was three years employed before it was deemed necessary to detach the scales: on the sides this is extremely difficult to manage, the water-ways seldom exceeding four inches, and rarely being so wide.

I was led to imagine, from the appearance of the boilers after the first voyage, that they could have been employed indefinitely without any considerable scale; but experience has shown, that to a certain extent it must be expected: in the sixth year, the vessel being actively employed in the Mediterranean, the boilers were scaled about once in three months; the number of entire days at sea in that time being from sixty to seventy. The tops of the tubes were not always cleaned, attention being paid to remove all scales that might be partially detached from the sides: no time was wasted in removing the scales by scraping or chiselling them in minute portions, the loose or easily detached pieces only being attended to.

The sides of the fire-places have seldom more than patches adhering to them here and there, and of course are easily cleaned. By the above operation it will be readily seen that the surfaces of the flues would be constantly approaching their original state; that is, each scale of five or six years' formation leaves the copper bare; and the more frequently the boilers are scaled, the greater opportunity is afforded the parts to detach themselves.

I should recommend that boilers employed beyond a limited period, regulated by the incrustations, should be scaled once a month while actively employed; the operation would then be simple, and would not occupy above two or three days to do it effectually: no violent measures need be adopted, for reasons already given; and the matter removed always exceeding that deposited, the condition of the flues, as before observed, would be constantly improving, as regards the parts which are exposed to the water.

ON THE CONSTRUCTION OF COPPER BOILERS.

21. Copper boilers, to a certain extent, have fallen into disrepute, three or four sets having been cut up after employment in the Government steam vessels. The

truly states, the fire-places of iron boilers required repair "*almost invariably at the conclusion of every voyage,*" he alludes to the system of external condensation, which had been nearly perfected by various inventors, but chiefly by Mr. Samuel Hall, by means of his patent condensers, at an expenditure of ingenuity, talent, perseverance, and withal money, that has seldom been equalled by any other individual. A glance at the four Plates of the 'Wilberforce,' XL. to XLIII. of this Division, will be alone almost sufficient to justify this assertion. It is, however, well known that the advocates of the simpler but still more expensive plan of *copper* boilers succeeded in obtaining the approval of the Admiralty of the day.

See additional Note, D, for further illustration of this subject.

fire-places were exceedingly good, as well as the top and side plates of the flues, except in some instances where permanent injury was sustained by incrustation, the result of negligence.

Now, in every instance the destruction of the bottom plates of the flues was the prominent cause of their disuse. Hence, after much inquiry and observation, I suggest that more care and attention than that usually paid in the construction of iron boilers should be observed in fitting the bottom of the flues and shell of copper boilers; in fact, too much pains cannot be taken in the first place, as it is amply repaid in the sequel. The rivet-holes through the lower 'angle irons' and plates should exactly coincide, and the rivets properly fit them. One of the greatest present nuisances is the defects of rivets; many of them actually bend in the disfigured holes in the act of clenching; they certainly cannot fill a hole of a different figure. The riveting merely swells the point, and not the body to any extent, as I have witnessed in many instances: the result is, that water arrives at the clench of the rivet immediately, which, if not well worked, seldom prevents the water from oozing through. The rivets should, in these places, be well worked in the style observed by coppersmiths. The junctions of the 'angle irons' should be carefully fitted; for neglect of this is almost irremediable: and the caulking or chincing should be eventually executed with the greatest nicety, as no opportunity is afforded, after construction, of properly making good any defects consequent on neglect, or want of sufficient care in this stage of the manufacture.

22. In IRON BOILERS, when water is first admitted after construction, hundreds of 'weeps' or channels in the plates and rivets, whence water oozes, are totally disregarded; the most important only being stopped mechanically; the rest are stanchd merely by the rust the water has formed in its passage, and the bulk of the oxide being greater than that of the original metal, lingers where it is formed, and thus becomes a perfect iron cement, and the boilers are tight: not so the COPPER BOILERS; for the water, attacking the metal in its passage through, forms the carbonate of copper, a clear transparent solution, which is not crystallized till deposited on and spread over the bottom of the flues, where it continues its work of destruction. The track of the water, as exhibited in defective rivets, precisely resembles the tortuous operation of the worm in fruits or wood; being partly in the plates and partly in the rivets, so as in almost every case to require the hole to be much enlarged, in order to remove the defect prior to the substitution of screwed rivets, which at the best are a poor substitute for a rivet of the original kind.

I have found that when sufficiently acted on chemically, the above observations equally apply to the joints of the plates with the 'angle irons,'¹ the apertures

¹ By using the term 'angle iron,' thus literally quoted by Mr. Dinnen, it does not necessarily follow that there is any *iron* in the article so designated when used for a copper boiler. This remark is scarcely

formed between them being sometimes entirely in the plate, which is thus decayed so as to receive copper pins of considerable size. This is the worst state of the evil; for the water by its pressure, in addition to that of the steam, acts mechanically as well as chemically in forcing its passage, which, if not timely stopped, will certainly eat transversely through the plate. It is also worthy of note, that the flues are found perfectly tight over-head and along the sides; the lower parts and the 'angle iron' of the bottoms only, and that in spots difficult of construction, yielding to the action.

After a lapse of six years of active employment, I can safely pronounce the parts above the bottom of the flues and fire-places, exposed to the constant action of the fire and water, to retain nearly their original thickness; I say nearly, because the deficit cannot be actually observed or estimated unless by weight. From the line, however, which the usual length of voyage permitted the salt to accumulate downwards to the bottom of the flues, that is, to the extent of thickness of salt deposited, corrosion has evidently taken place so much as to threaten the security of parts originally well manufactured, even in the face of caulking, &c. This evil necessarily continued in action for some months in the Mediterranean, when employed between Malta, Egypt, and Syria, on an average of twenty to twenty-four days per month at sea, in the total absence of Roman cement; which, when procured, again kept the flues tight and dry. The advantages of the cement, here exhibited, suggest its use not only when a boiler is defective, but when perfectly new.

I should propose, that when tried and found perfect, the flues should be well cleaned, and a flooring of cement applied by proper persons, so as to include the 'angle irons;' tiles should then be embedded nicely, forming a perfect surface from the chimney to the furnace, or, which was the method I adopted, a fillet should be applied all round the 'angle irons,' with a flooring beneath the funnel. Thus the water from the chimney, impregnated with the matters of the soot, would be entirely prevented, in the beginning, from acting on the bottoms of the tubes; and any spot beneath, being disposed to 'weep,' would be prevented till it had been permanently filled with sulphate of lime or other matter, which, on the contrary, would be forced onwards into the bottoms of the flues if water could freely pass. It would have another advantage,—it would afford facility in sweeping the flues, and would occupy the intricate parts, from which the soot is never thoroughly cleaned. No very material loss of heat would be sustained by this application, the fires not being calculated to reverberate downwards to a great extent: on the contrary, I

perhaps required here, where an earthen pot is commonly called a *pan*, and an iron pan a *pot*, or if set in brick-work, generally a *copper*, but may be useful to those of our Transatlantic, as well as Lancashire and Yorkshire readers, who yet prefer calling things by their proper names.

have often sent wood into the flues, which has been withdrawn, merely charred; a proof that the bottoms of the flues — those leading directly from the furnaces excepted — contribute little to steam generation, even before any deposition of soot has taken place.

I think it probable that 'weeps' in the tops and sides of the flues, before alluded to, are first checked by the intensity of the fire acting on the water as it oozes, when the lime subsides and hardens to cement; for there is no reason why 'weeps' should not have existed in equal abundance in these places, as well as in the bottoms; but it is certain that none have been exhibited.

The bottom and lower parts of the shell of the boiler should be treated with as much care in construction as it has been suggested to pay to the bottom of the flues; and the chimneys should invariably be made of *iron*, to step on a cast-iron ring fitted to the top of the boilers. The cast-iron ring does not seem to be affected by the copper; its situation accounts for it.

23. COPPER FUNNELS have been a complete failure in every instance of their adoption; they are rapidly corroded within the air casing, so as in one or two instances to have been crushed by the effects of a gale of wind. IRON FUNNELS decay principally in the parts on which the waste steam operates, and these plates require renewal more frequently than the rest; therefore it is better to carry the waste-pipe level with the top of the funnel: coal tar, or red-lead, or a mixture of both, is the best varnish I have known to be adopted for funnels, which with care may last five or six years.

In conclusion, I confidently express my opinion that COPPER BOILERS are very far superior to Iron for marine purposes; and that if the necessary precautions in construction be observed, they will run for a considerable time without giving trouble of any kind. Tinning the bottom plates, as observed by Messrs. Maudslay and Field, I should certainly recommend; it will remove the chance of decay to a certain extent. Large pieces of iron have frequently been sent into the flues by me, which have been completely decayed in a short time; no doubt with some good effect to the copper, but without the possibility of being estimated. If the cause be removed by attention to the suggestions on construction, a patch will seldom be required; consequently delays will be seldom experienced on account of the boilers. The original cost is nearly as three to one on the iron; this ought not to deter companies, or the proprietors of foreign steam vessels, where the means of repair are not at hand: besides, when unfit for further use, they will always make a good return as old copper; an old iron boiler being, in general, worth little more than the cutting up. Copper, again, is a better conductor of heat than iron; and if the advantages of incasing marine boilers with non-conducting matter were properly considered and availed of, boilers might be reduced in capacity, weight, and expense,

to the obvious account of the proprietor, and to the increased stowage of fuel.¹ More might be said, but the above, coupled with the fact that the shell will scarcely ever be injured or decayed, will be sufficiently demonstrative, when iron boilers frequently require extensive repairs of the shell or casing, either from water passing by the funnel on the top of the boiler, or from the unavoidable leaks of the deck and comings around the steam-chest; also the shell is decayed, from the salt, &c., on the line of stoke-hole plates or flooring, as well as in the neighbourhood of most of the stay-bolts on the back and sides, — the bottoms being often totally decayed; and these are parts which, from their situation, cannot be attended to conveniently. The above facts are notorious in iron boilers, when in many instances no other defect has existed; indeed, copper boilers appear to be almost invulnerable in those situations where in iron boilers, whether employed or not, the work of decay is constantly going on. Many cases of delay and incapacity could be mentioned from these causes alone, when important public service was most urgent, not to mention that of individuals.

¹ Very much that is said in this paragraph in commendation of copper, as being, in many respects, a superior material to iron for marine boilers, it is impossible to controvert. There is, however, one objection to be made, and we think, a fatal one; if we could for a moment suppose the possibility of arresting all further progress in invention, to say nothing of improved workmanship and greater experience in the management of steam machinery,—in short, if we could imagine a *status quo* for steam travelling in 1838, when this Paper was written, or even in 1848, any more than in 1828, then indeed we could have no choice but to agree with Mr. Dinnen's conclusions. Fortunately, however, there is no 'finality' in steam. Not to 'go-ahead' is to go back!—Even a Government Navy Board, with its immense power of resistance to improvements, has been compelled to give way successively to the adoption of tubular boilers,—direct-acting engines,—iron ships, and lastly screw propulsion, as well as to a host of minor valuable innovations that are being constantly thrust upon the attention of the Admiralty, by the perseverance, though often to the ruin, of numerous individuals. During the progress of all these improvements, there is one in particular going gradually and quietly forward without any one to recommend it; and although not so conspicuous at present, its effects will be more certain perhaps than those of all the rest put together, and that is the adoption of a higher pressure of steam. To the advantages to be reaped in this direction there is no limit whatever except in the strength of the materials composing the boiler.

Had it been possible to have kept the maximum pressure of steam down to what it was ten to fifteen years ago, namely, at 5 or 6 lbs. per square inch, then this Paper might have been stereotyped, and these notes would not have been wanted. But as it is, when instead of 5 we have commonly 15 to 20 lbs., and the Americans 20 to 30 lbs. per square inch in the marine boilers of 'low' pressure condensing engines, the question of copper boilers is virtually disposed of. The expense alone would be sufficient to determine this point. Instead of its being for copper and iron in the ratio of 3 to 1, as stated by Mr. Dinnen, for really *low* pressures—the disparity for equal strengths to resist *high* pressures is more nearly as 6 to 1. That is to say, in a large war steamer, it would be between £6000 to £8000 in the one case, and £30,000 to £40,000 in the other, a difference sufficient to enable us to equip five ships with iron boilers against four with copper ones for the same amount of money. And as money is the main "sinew of war"—other things being equal, the result is obvious. In this respect also, what is true of warfare will also hold good for steam vessels employed for commercial purposes.

It is a common practice in many vessels to throw water into the ash-holes, to cool the cinders prior to sending them up; the salt, which adheres to the ash-pit in consequence, has sometimes destroyed the bottom plates, when every other part of the boiler was sound. I have seen some instances recently, where the water discharged from the gauge-cocks is conducted there by tubes; the men avoid being scalded by this arrangement, at the risk of the destruction of the ash-pits by the brine there deposited. Water in ash-pits has a cooling and draught-exciting property on account of the evaporation; but it ought on no account to occupy the ash-place of an iron boiler, unless a cistern, constructed for that purpose, be appropriated for its use.¹ In copper boilers I have disregarded the water arising from 'weeps' in the ash-pits, no chemical action taking place here, when employed at sea, on account of the frequent removal of their contents. The intrusion, however, of sea-water into the ash-holes, no matter from what cause, ought by no means, in any boiler, to be encouraged.

My object having been to show by comparison the advantages of copper over iron boilers for marine purposes, and to set in a proper point of view the deposition of salts, their effects, and the means of avoiding the same in boilers, as now adapted and arranged, I think that for the future, as regards these matters, all vague speculation, with practical men, may be laid aside; the evils complained of having been shown to arise, in *all cases*, both from want of sufficient care in construction, and in the ultimate management.²

¹ The cooling and "draught-exciting property" of water in the ash-pits should always be taken advantage of in the manner stated. Besides improving the draught and cooling the fire-bars, for which we are yet without any adequate theory, the practice, to the certain knowledge of most engineers, also saves fuel. Of the rationale of the process, however, by which fuel is saved by such means, unless that of a partial decomposition of the vapour be admissible, we are left still further in the dark by chemical philosophers and writers; some contenting themselves by simply denying the facts, or rather asserting that the direct contrary result must take place owing to the latent heat carried off by evaporation. Most popular scientific lecturers on this account take great pains in instructing us to avoid all wet or damp about the ash-pits, and particularly to avoid wetting the coal. Both practices, however, are, in my experience, eminently conducive to economy, and the latter in certain cases to a very considerable extent.

² In the strong case here made out in favour of copper for marine boilers, though now invalidated by increase of pressure during the great lapse of time since the article was written, as I have attempted to show in the previous note but one, the strongest point is doubtless the superior conducting power of copper over iron, it being nearly as $2\frac{1}{2}$ to 1. The particular bearing of this fact upon the durability of the side plates of boiler furnaces generally, I several years ago, with Mr. Dinnen's valuable assistance at that time, took some pains to investigate. The results of this investigation, which were in favour of copper, are given in the additional notes D and E.

In referring to the above-mentioned investigation, which was undertaken expressly in support of the opinions I then held in common with Mr. Dinnen, in favour of copper, candour compels me not to omit

CIRCULATING PIPES, DAMPERS, &c.

24. Circulating pipes, that is, pipes of communication between boilers when more than one is used, are generally fitted with a small bonnet for the purpose of cleansing. The situation of these pipes generally is such as to deprive the engineer of examining them at all times: the pipes on the sides are concealed by the coal-boxes; those abaft and forward being usually at hand.

Now, in many instances, the feed, or water for the supply of evaporation, is injected into the front boiler or boilers, those abaft depending mainly on the condition of these pipes, through which they are intended to be supplied. Instances occur where the flues have been much burnt and injured from incrustation, while the fire-places situated in the front boilers were in perfect order. The pipes have been choked, and of course a sufficient supply could not be maintained in the after boilers; hence the deposit and permanent injury. The coal-boxes, therefore, and other obstructions, should be so modified and cut as to afford convenience for examination; which should take place *at least* on the return from every voyage, the small bonnet being removed from each pipe, and its condition strictly looked into. If duties be ever so pressing, commanders should always afford time for, and engineers strictly fulfil, this most important one.

Circulation of the water through all the boilers should never depend entirely upon the pipes, but should be maintained moreover by free communication above the flues; and these communications should be cut as near the surface of the flues as possible, in order that the blowing off one boiler may to a certain extent affect the condition of the water in the rest. The 'Flamer' and some other of the Government steam vessels have been fitted with two tiers of connecting pipes, the upper ones three inches below the level of the flues, and thereby favouring the circulation desired. Cutting the passages through the joining boilers, for sea-going vessels, sixteen or eighteen inches above the flues, has been deemed necessary to prevent the water from leaving the flues of the side boilers when rolling: experience shows this precaution to be unnecessary, the temporary inclination of the ship never exposing the flues to injury, when rolling simply; and no extraordinary

mentioning other facts of importance that have come to my knowledge since the time referred to, that may be necessary to illustrate both sides of the question. One such fact, said to be well known to persons conversant with the interior of copper boilers when much used at sea, is the frequent existence of channels or grooves found to run nearly parallel to the vertical joinings of the plates, about half an inch from the edge of the overlap of the plate, reaching to nearly half the depth of the flue in the vicinity of and beyond the bridge. I have witnessed some of these corroded furrows or channels, apparently produced by chemical action, which have extended through one-half the thickness of the copper.

angle is to be anticipated, such as canvas would effect, it being sufficiently understood by commanders who have the least acquaintance with steam vessels, that the sails are a disadvantage when they give the lee-wheel too much depression. A single boiler may be at least eight feet wide without any risk, with the ordinary quantity of water above the tubes; indeed nearly twice this width may be trusted safely, as instanced in front boilers containing four fire-places of considerable size. A wash-plate fitted into the middle of the after boiler, fore and aft, upon the flues as high as the water line, would answer every purpose of preventing the water from entirely leaving the wing-flues, on taking a lurch: the same arrangement may be adopted in a front boiler; but it is not absolutely necessary, the water above the tubes having a greater depth, generally, than that of the other boilers.

25. Boilers for steam vessels of great or considerable power are necessarily constructed in two, three, or more parts: these parts are best arranged when they are the entire length of the boiler fore and aft, their ends forming the front and back of the whole: thus the longitudinal boiler precludes the inconvenience liable to connecting pipes in the coal-boxes, and to the heavy rolling of the vessel causing the water to recede from above the flues. Each boiler can then be entirely distinct from its neighbour, having its own feed and blow-off pipes, and containing its own fire-places and flues; the smoke and heated air arriving at the upper surface of the boiler, to the chimney, before it mixes with that from the other boiler or boilers. The base of the chimney, in the case of three boilers placed side by side, may be of an elliptical or oblong, instead of cylindrical figure, covering the mouths of the flues, which should *each* be furnished with a damper, fitted directly on the boiler, and quite distinct from the funnel; having a communication by levers with the engine-room in front of the boilers, and thus being at all times under the control of those below.

When a DAMPER is fitted in the chimney, it will inevitably be carried away with it in case of accident, and the ship exposed to fire: an instance occurred in the 'Thames' Irish steamer, in the Channel, where the vessel was nearly on fire from the sudden loss of the funnel by a ship running on board her in the night. I have seen funnels carried away in harbours, by getting athwart hawse of other vessels. Accidents are not uncommon at sea, particularly when the funnels are of copper, which, decaying rapidly within the air casing, is less calculated to resist a gale than iron. I have frequently been surprised that funnels stand so well as they do; preventer stays are often necessary: therefore, fitting dampers in the chimney should by no means be adopted.

To complete the arrangement, each steam-pipe should have a COMMUNICATION VALVE; or a valve should be fitted on the top of the steam-chest of each boiler, where they join the common steam-pipe; so that either boiler may be employed,

without at all depending on its neighbour ; the safety-valves, as usual, having one common waste steam-pipe. The advantage of this mode of construction is obvious, when it is understood that in a gale of wind, or in the case of a ship of war cruising with a squadron by steam, not half the power can be employed with effect ; then one boiler or two can be dispensed with, according to necessity, with a saving of fuel, almost in the ratio of the consumption of the boilers unemployed ; I say almost, because a certain portion of heat will be lost by radiation, and by the absorption of the contiguous boiler. In going head to wind the above advantages are most felt ; for the number of revolutions at full speed, of *sea-going* steam vessels, varying from thirty to twenty-two per minute in smooth water, within the limits of 80 and 200 horse-power inclusive, and when contending with a strong gale ahead, the speed being reduced to eight or nine revolutions per minute in most cases, it will be seen that the demand for steam is wonderfully less in the latter than in the former case. There being two engines employed, and each making two strokes to effect a revolution of the wheel, four cylinders full of steam are consumed in the same time, though of a pressure less than that on the safety-valve : independently of expansion, the pressure of the steam is diminished by condensation in the passage through the steam-pipes and jackets, which, by the bye, is very considerable in those vessels fitted with the cylinders forward. Now, the loss of heat by radiation from the steam-pipes, cylinders, and slide casings being constant at all speeds, the saving, by dispensing with the use of one or more furnaces, will fall short of the expectations raised by their temporary disuse, inasmuch as the remaining furnaces require to be urged. A furnace cannot be thrown out of use with economy, when the fuel contained in the remainder must be disturbed often before it is fairly consumed ; and this must be the case, unless the mouth of the furnace unemployed be closely covered in, the in-draught of cold air through the same being a great drawback on the effect of the other furnaces : hence the greatest effect will be produced when an entire boiler is thrown out of use. When one furnace only of a boiler could be dispensed with, I have often found it most economical to burn the ashes of the rest therein, mixed with a little coal ; and when too dirty, or the draught too much impeded by clinkers, another furnace performed the same office, while it was thoroughly cleared out, and became an active furnace ; and so on in turn with the rest.

26. Since it has been shown that the consumption of fuel, on principle, should be expected to be in proportion to the revolutions of the wheel, but that in practice it is found to be much greater,—the masses of the boilers, cylinders, pistons, &c. &c. having at all speeds to be maintained by the *steam* at its own temperature,—it follows that the less these parts are exposed the better ; and if radiation were prevented by completely covering the boilers, steam-pipes, and cylinders with non-

conducting materials, the saving of coals only would soon amply return the cost,—particularly in sea-going vessels, where gain cannot at all times be effected by bearing up for a port, but where the gale must be struggled with for many days together,—not to mention the constant injury sustained by bulk-heads, comings, and decks, by the overpowering heat to which they are submitted. The frequent repairs and renewals of these parts only amount to no small cost per annum in Her Majesty's steam vessels on foreign stations.

Economy of fuel on long voyages has not, I am prepared to say, met with the attention it deserves: stokers consult their own convenience; and as long as they keep *plenty* of steam flying off to waste, they are seldom called to account: as to myself, I have found the greatest difficulty in obliging them to keep the fires uniformly. In a gale of wind, and then only, when the labour was little on the fires, and when it became a consideration with every one, both on deck and below, to eke out the means of arriving at the destined port in safety, the fires were minutely attended to, and the fullest effect obtained at the least possible expense: a few *clinkers* only, and *no ashes*,—which should never, in iron boilers, be allowed to remain longer than two hours in the ash-pits, or in contact with the boilers on the stoke-hole plates,—were thrown overboard twice in twenty-four hours, when such discipline was observed, and this with the Welsh coal. How much greater would the gain be *at all times*, if the oppressive heat, which drives the fire-man from his quarters now, were removed, so as to permit him to dispose a *less* portion of fuel to a wonderfully increased advantage! ¹ These considerations are by no means

¹ That stokers *will* “consult their own convenience,” as they have a right to do, is not very surprising when no one else, with very few exceptions, appears to do it for them. These men are, in fact, under the present system, really the prime movers of the ship, almost as much as were those who rowed the galleys of the ancients; and so long as the systematic opposition, on the part of Navy people, to the adoption or extension of mechanical improvements continues, nothing can be more certain than that the difficulty complained of, “in obliging them to keep the fires uniformly,” will continue also. Besides, in studying the welfare of *number one*, it is notorious that stokers have numerous examples in high places. It is, however, but justice to state, that, speaking of the practice at least of only a few years ago, there is a wide difference both in the selection and treatment of the fire-men in the Government and in the merchant service; and the reason which is usually assigned for the superior attention paid to the stokers in the Royal Navy is, that unless the comfort and conveniences of the men were in some measure attended to, the interests of the service would suffer considerably by the difficulty of replacing them, when wanted, in vessels remaining a long time on foreign stations; whereas in the merchant service no such difficulty can occur, the vessels frequently, or at short periods, returning home, or to ports where plenty of the ‘raw material,’ as it is expressed, may always be had cheap. Such being the condition of the ‘labour market’ therefore, speaking in a mercantile sense, any attention to the health of the men, by devoting more space and ventilation to the stoke-hole, instead of carrying an extra ton or two of measurement goods, ‘would not pay.’ Hence also the preference generally given by intelligent fire-men to the Government service.

visionary ; the people in Cornwall understand them well, and profit thereby to a considerable amount. I have, on a summer's day, found it sensibly cooler in an engine-house closed, containing a cylinder 80 inches in diameter, and 10 feet stroke, while the steam-gauge indicated 34 lbs. per square inch on the safety-valve, than I experienced without : the boiler-house nearly the same. Is not economy in fuel as loudly called for in marine engines, without reference to stowage, health, and the labour and dirt of shipment?

The advantages above proposed are now carried into effect to a certain extent in Her Majesty's steam vessels, by coating the boilers, whether of iron or copper; with 'felt,' laid on a thick covering of a mixture of white and red lead ; the same treatment has been observed with regard to the sides of the respective boilers where they come together, when smoke-joints do not interfere : the advantage of this does not consist only in the preservation of these sides, so liable to decay from the water which descends there leaving its salt adhering to the plates, but it operates to prevent the heat of one boiler from being transmitted to another when not employed ; indeed, the practice of coating boilers of marine engines was observed as far back as 1818 in the 'Caledonia,' Mr. Watt's private steam vessel, and also in the 'James Watt' in 1823 :—the cylinders of the former were also coated in the same manner and covered with reeded mahogany. By combining the arrangements before mentioned, so as to have the respective boilers and flues distinct, smoke-joints may be entirely dispensed with : these are generally dangerous, although often unavoidable, both from the size to which the boilers are required to be carried, to meet the power of the engines, and from the necessity which sometimes exists of adapting them to the peculiar construction of the vessels.

27. From the frequent necessity of opening the furnace-doors, when under weigh, to replenish and arrange the fires, a large portion of cold air is allowed to pass through the flues : this ready passage for the air checks its entrance through the bars of the adjoining furnace or furnaces, and in most instances throws them for the time nearly out of use : thus the boilers are not only deprived of the effect of the open furnace, but, to a great extent, of all others connected with the common flue : this is so certain, that boilers having four furnaces joining in one flue, as formerly fitted to vessels of 100 horse-power and upwards, have been supplanted by others in which two furnaces only discharge their fire into a flue which meets that of the other two furnaces at the chimney, having traversed the water separately before they meet. The former plan of boiler is always remarkable for a bad or indifferent draught ; it requires more area of heated surface to generate sufficient steam, occupies of course more space, contains a larger quantity of water, and is, in addition, considerably heavier than the latter style of boiler, which is distinguished for its power in producing steam, and for the

ease of working it. Hence it follows that the more distinctly furnaces perform their work, the greater the effect obtained; but this has its limits; for if a flue is too direct, a great portion of heat passes up the chimney without effect, the fire not having traversed sufficiently through the water to be absorbed by it.¹ In land engines this effect is not experienced, the fire passing around as well as through the boiler; while in vessels the fire must be entirely confined to the flues, which are surrounded with water.

Some of the best judges of the construction and working of marine boilers recommend that the fire should be divided by as many furnaces as possible within certain limits, in order that the feeding a fire should not occupy too much time, and that it might be performed more frequently, and in consequence more regularly; and, it is presumed, with better effect, on account of a less portion of cold air being permitted to pass through the flue at a time. When *three* such furnaces are employed instead of two, (for it has been observed that four are decidedly objectionable,) which communicate with a common flue, it is evident that there are always two furnaces in action, while the third is being entirely cleared out; an operation which at sea must be performed at least, in turn, once in two hours, the fire-door being open during the operation, and a considerable quantity of cold air afterwards passing through the grate until the relay of coals is in a proper state of combustion. Here the three furnaces have a decided advantage over two of the same area collectively, in maintaining the power of the engines during the disuse of one of the number: but if the two furnaces be managed properly, want of steam during the above operation will rarely be felt. Of course these observations are

¹ Excepting only as relates to certain arrangements of double, or divided, furnaces, for consuming smoke, Mr. Dinnen's averment that "the more distinctly furnaces perform their work, the greater the effect obtained," ought to be received as an axiom in boiler-making. It is scarcely possible for a flue to be "too direct," although it may be true enough that in a short direct draught a great portion of the heat passes up the chimney, though certainly not "without effect," as it is so common to suppose; and the effect, *always beneficial*, is indicated in the increased draught, by which a greater degree of heat is generated in the first instance. With a crooked, indirect, and consequently bad draught, it is also no doubt certain that much less heat passes off to waste in that way, but only because the heat is *not there*, to begin with. Engineers are continually forgetting, that heat is not a substance of which a certain quantity is thrown into the furnace with a given proportion of coals. Heat has to be *created*, so to speak, and the fuel is only one of the means used for that purpose,—the oxygen of the air, which costs nothing, being the chief requisite, and which all experiments agree in proving to be a much better measure of the heating effect produced by combustion, according to the quantity used, than is to be attained by measuring the amount of combustible matter consumed. When, for instance, the draught is in full force, with a sufficient supply of fuel and a temperature of, say 3000 degrees in the furnace, we can well afford to throw away, to "waste" as it is called, some 200 or 300 degrees up the chimney, thus perhaps doubling the heat of the latter, and still produce a more economical result than can be obtained by a bad draught that will not raise the temperature of the furnace to 2000° at the commencement, although we "waste" nothing.

referred to vessels of such power as to have, at least, two distinct boilers, or two distinct sets of furnaces and flues in the same boiler, so that you have the full effect of one or more boilers or sets of furnaces, without any drawback, at all times. From the necessities of construction, *three* furnaces cannot *directly* discharge their fire into a flue whose width is less than that of either of the furnaces individually : the fire having, in one furnace at least, to cross, to a certain extent, that of another before it can enter the flue, this furnace is least active when either of the other furnace-doors are open, the cold air directly entering the flue retarding its effect : the fire of this furnace moreover, when all are in full force, acts directly on the side plates of the cross flue opposite, before it passes with that of the other furnaces into the common flue ; the consequence is, that if the boilers are partially incrustated, these plates must be the first to give out, next to those of the furnaces, of which there are many instances. Hence when three furnaces are employed, the flue should be deflected as much as possible, to accommodate each of them.

28. From an extensive examination of the boilers of long sea voyage, I am led to the opinion that the fires act more destructively on the sides of narrow furnaces than of those under similar circumstances of greater width ; it may arise in a great measure from the fuel being heaped up more thickly in the former than the latter : the air not being able to penetrate the mass well in the middle, then passes up the sides, urging an intense flame to act thereon ; this cannot take place so effectually in a wider furnace. A furnace that is very long cannot be properly managed by the fire-men at sea : it has every chance of being overcharged, more particularly if the boilers keep steam easily, because then they require less attention, and are charged so as to last as long as possible for the accommodation of the man ; and this practice cannot well be overruled night and day, unless engineers neglect other duties ; for it would be necessary to be constantly in a stoke-room for the purpose. I should say, that if a furnace be six feet in length, it should not be much less than three feet in breadth, to afford a fair chance for firing with as little injury to the side plates as possible, and with the means of keeping the fires in the required condition for the greatest effect : furnaces should not be carried beyond this length more than can be avoided ; it is not necessary that they should ever be wider than three feet, indeed it would be inconvenient ; but the nearer it is approached in width *for various powers*, I think, the better. By adopting short and wide furnaces, short firing-tools become necessary, and of course short stoking-room, thereby gaining on the entire section of the ship for the stowage of coals abaft. The *crowns* of the furnaces, *whether of iron or copper*, never decay, and rarely alter their figure, *if arched*, unless the water is allowed to descend below them.¹ In some of the most neglected and most injured boilers that I have seen, the crowns of the fire-places have remained

¹ See additional Notes D and E.

perfect, when every other part has been attacked by the fire: it can be accounted for by the ready transmission of the heat, which is obstructed more on the sides, from the accumulation of scales and the increased difficulty of removing them.

29. In the arrangement of *plates in the furnaces*, perpendicular seams are bad, and in long voyages are certain of injury from the fire; the quantity of metal at the joinings or seams causing an unequal expansion, and retarding the transmission of heat. Plates the entire length of fire-place may be employed, having their seams beneath and in the direction of the bars; the upper seam, when the furnaces are large, being as much above the fire as possible; but, on this subject, opinions are divided, some still preferring the former method of construction. Plates of copper may be manufactured with certainty of the entire size required for the sides, in 50-horse boilers; but iron plates of such dimensions could not be depended on. Iron plate for furnaces should be manufactured of the best material that can be obtained; additional expense for such would be amply repaid. The plate used for furnaces mostly owes its premature destruction to the great thickness usually employed: it thus conducts heat more slowly, and is necessarily more heated than thinner plate; besides it is much less likely to be sound than the latter, although of an excellent exterior, which conceals the defects of manufacture.¹ I some time

¹ Besides the thickness of the iron there is another cause for the over-heating the side plates in furnaces, of some importance to be mentioned here, and that is, their usual *vertical position*. There are many facts, relative to this subject, well known to those practically acquainted with the repairing of boilers, could they be all safely told, of more value to Steam Navigation Companies perhaps than any conceivable number of new plans. The subject is important, because it involves a principle applicable to all kinds of boilers without distinction, even to those of railway locomotives, as will be seen by referring to my Paper on the 'Evaporating Power of the Locomotive Engine Boiler' in the first division (A) of this work (art. 20, page 7).

In the article just referred to, it is shown how much more efficacious, in generating steam, is any portion of the heating surface which approaches to the horizontal position over the fire than that which is vertical or nearly so. In boilers fixed in position, as well as in river steam boats where there is not much lateral oscillation, this difference in effect is very apparent; and, with some modification of circumstance, it is also equally observable in marine boilers at sea, but with infinitely greater effect as respects their durability.

The difficulty always experienced in causing heat to pass in a transverse direction through the upright side plates of furnaces and flues, is generally due to the intervention of the minute bubbles of steam as they rise from the lower portions of the heating surface upwards; a continuous thin current of steam then passing between the heated plate and the water requiring to be heated. The interposition of this stratum of steam, however insignificant in extent it may be, effectually prevents the necessary contact of the water required for keeping the plates at a sufficiently low temperature, which consequently are thus liable to become overheated and eventually burnt out.

The above paragraph is nearly in the precise words used in the last published edition of my 'Essay on the Boilers of Steam Engines,' and is presumed to be sufficiently explanatory of my theory of the main cause of the premature destruction of the side plates of the furnaces and flues of marine boilers. If in

since examined, in a foreign port, an excellently constructed boiler of a 200-horse marine engine, and of the very best material, which had been comparatively seldom employed during eighteen months after construction: the interior of the boilers evidenced the greatest care and attention, but the side plates of the fire-places, from the bars upwards, required to be replaced, from no other cause than that of being too thick. These cases are very common, as before observed, in Her Majesty's steam vessels between Falmouth and the Mediterranean, as likewise those employed on other stations, which need repairs in these places several times before the boilers are required to be taken out, from actual decay.

Many have been formerly misled as to the cause of injured boilers. I have witnessed ingenious expedients of negligent persons to account for the same, in the

order to prescribe a scientific remedy for an acknowledged evil, it is first necessary to have a correct statement of the causes concerned, as well as a true account of some of the most plausible though abortive remedies hitherto attempted, it will be impossible to withhold a digression on this subject, however tedious it may prove; in fact it would be unjust to do so, for reasons which will presently appear.

The only method of putting an end to this prevailing error in the construction of boilers is to induce boiler-makers either to make all internal furnaces and flues circular or oval in section, or, if flat-sided flues be continued for low pressure, simply to incline the sides towards the fire, at an angle of not less than half an inch per foot; that is, a flue four feet deep ought not to be less than four inches narrower at the top than at the bottom. If the space in the vessel will admit of a greater inclination of the sides of furnaces and flues than this,—say one or two inches per foot in depth,—so much the better; the steam will then rise and be driven off more rapidly from the surface of the plate, which will then also be kept at a comparatively moderate temperature by more perfect contact with the water,—thus avoiding the overheating, blistering, and burning-out of the furnace plates, and all the train of evil consequences thereby ensuing, at one time so much complained of as being the cause of much opprobrium in the Steam Navy,—iron furnaces, then, “*requiring repair almost at the conclusion of every voyage*” between Falmouth and the Mediterranean!

Perseverance in error while a remedy is at hand which *costs nothing*, may well justify the repeated complaints of nautical men, as well as the attempts which some of them have made to correct the mistakes of marine engineers, or rather boiler-makers. I trust also to be justified in thus enlarging on this subject, though it be only to draw attention to the facts adduced in the text, which may be proved to every one whether at sea or on shore, and on which the *only true theory* for the position of the heating surface can be founded; satisfied that if right principles be thus established, correct rules for designing boilers will easily follow;—on this point, following the advice frequently given by my revered friends the late Dr. John Dalton and Mr. Peter Ewart,—that is, to persist in establishing correct principles whereby we make good boiler-makers as well as good boilers.

Now one can scarcely think it possible that practical engineers, having a perfect knowledge of all the facts on which the above advice is founded, can affect to mistake its meaning and purport,—or that they can continue any longer *conscientiously* to advise the retention of plans inconsistent with or in direct opposition to it. A scientific knowledge of the principles which ought to guide us in so important a subject is not a matter of individual loss or gain only, but may possibly involve the loss or destruction of a whole country whenever opposed by another power who know how to set a proper value on steam in time of war; a sufficient reason for speaking thus plainly.

presence of eminent engineers, who not having an opportunity of watching proceedings on a long sea voyage, were obliged, to a great extent, to take plausible reasons as their guide; viz. saltiness of the Mediterranean, &c.: allowing water to become too low in the boilers is too frequently the real cause, which, if copper, will soon exhibit the consequence. Thicker plate has been adopted, probably to resist the tendency to bend, but it only increases the evil. Plates for the sides of fire-places then should not, in the largest boilers, above the bars, be more than three-eighths of an inch thick; and in smaller boilers a less thickness would be preferable, as no oxidation takes place here, or even throughout the flues, of any consequence, above the mass of soot therein deposited. This fact is decidedly opposed to the *notion* generally propagated, that the iron rapidly imbibes oxygen from the cold air admitted, when the fire-doors are opened to replenish fuel: no more injury is experienced *practically* from this cause, than that found to be sustained by the exterior of a common culinary boiler, the plates not being sufficiently heated to imbibe a destructive portion of oxygen.

The lower part of the sides, and the bottom of the fire-place, should be thicker in all cases, the better to bear up against oxidation, which here takes place to a great extent, as likewise along the bottom and lower part of the flues; and the bottom of the boiler, and the lower portion of the sides, should be stouter than the crown, particularly in the wake of the stoke-hole flooring, where, as has been before observed, decay very rapidly takes place.

It has sometimes occurred that boilers of good construction have suddenly failed in generating the necessary quantity of steam for the engines, although the fires have been urged as usual: this unaccountable circumstance, after the strictest investigation, has been cleared up by the appearance of steam at the top of the chimney, instead of at the waste steam head. The UPTAKE, or portion of the flue which rises through the water of the boilers to join the chimney, has been found defective, so that the steam escaped above the water line, through the rent it made, directly into the funnel or chimney, the boilers in every other respect performing their duty properly: the uptake, therefore, should be thicker than the other portion of the flue, and should at frequent opportunities be perfectly cleaned and coated with some anti-corrosive: coal tar mixed with red-lead, and applied hot, I should recommend.¹

¹ Nothing can better illustrate some of the evil consequences arising from the improper position of the heating surface than this valuable testimony of Mr. Dinnen. Indeed, there can scarcely be a doubt in the mind of any practical man, that the premature destruction of marine boilers, in many instances, arises from the imperfect access of the water to the vertical portions of the furnaces and flues, in the manner described in the previous note. And more particularly is this the case where the steam is liable to become 'locked,' confined, and interrupted by injudiciously placed seams of rivets, or other

The SHELL or CROWN of the boiler, and STEAM-CHEST, suffer most from accumulation of dirt, and leakage from above. Steam vessels are necessarily much more

projections in the water-ways. The projecting breast, or uptake of the chimney, when that is placed below or about the water line, as was probably the case in the instance mentioned in the text, is a most vulnerable point on this account.

The best example of a mode of arranging the heating surface in a position to avoid the evils now pointed out, is perhaps in the uptake of the ordinary land boiler of Boulton and Watt, a section of which is shown in the annexed sketch, fig. 1, where A B is the surface of the water, and the numerous vertical

Fig. 1.

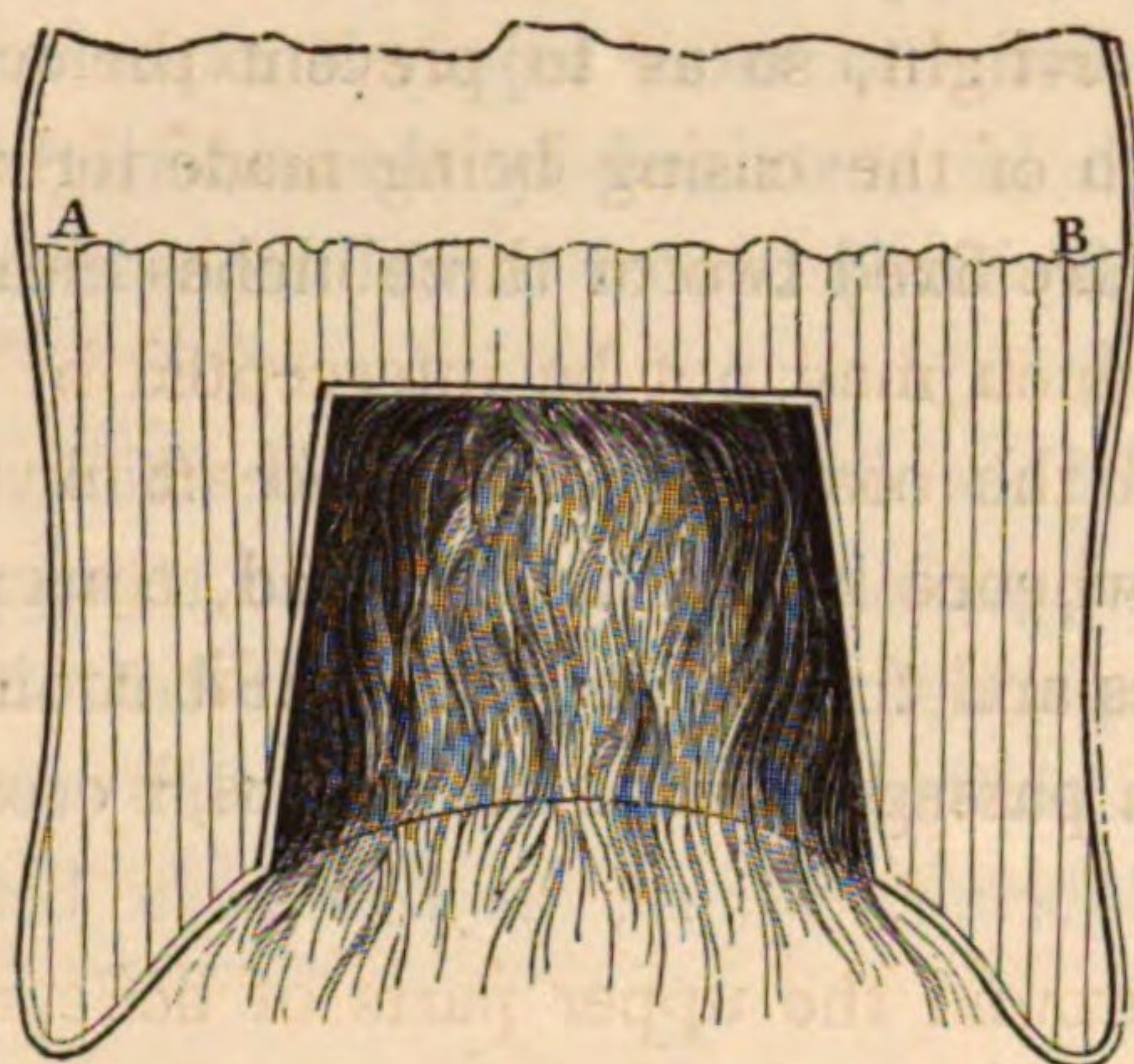
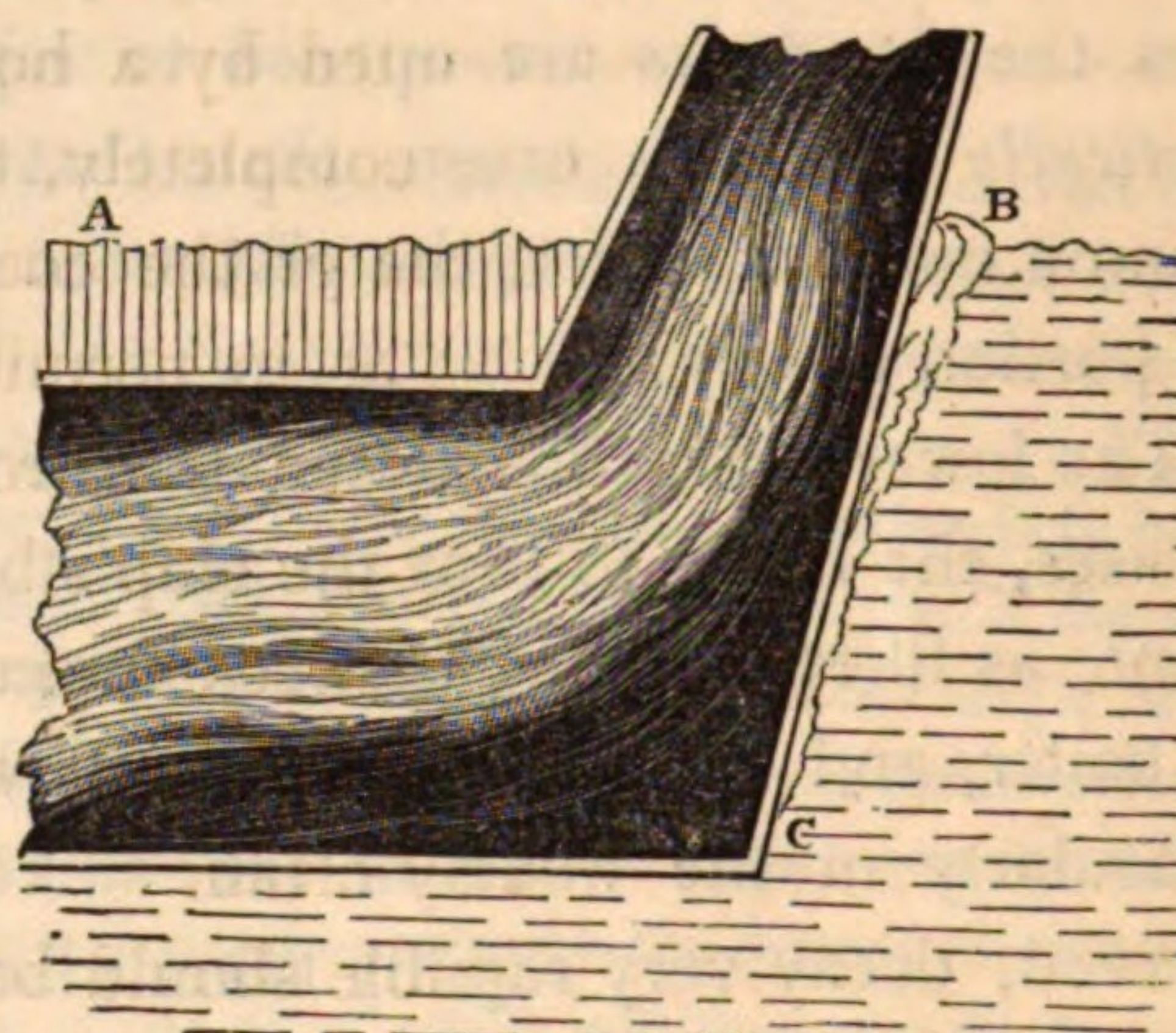


Fig. 2.



parallel lines show the directions uniformly taken by the ascending bubbles of steam that are raised from the different portions of the effective heating surface. A striking contrast to this state of things is shown by the position of the heating surface at C B, fig. 2, which represents the ordinary chimney uptake of a marine boiler, as commonly made only a few years ago; the heating surface in this case declining *from*, instead of inclining *towards* the fire, which is exactly the reverse of the foregoing. Hence the steam which rises from the lower portion of the flue effectually prevents all proper access of the water to the heated metal above it; consequently that part of the flue is found to decay very rapidly.

Much as I have pressed the great importance of avoiding this palpable error of construction on the attention of engineers, we are not yet entirely without some modern examples of it. An instance of the kind may be seen in an unexpected quarter by referring to the Plate containing the longitudinal section of one of the boilers of H. M. steam sloop 'Basilisk,' of 400 H.P; although, with this little oversight, the boiler is in other respects, and particularly as regards the very efficient mode of staying, an example to be studied.

Another instance, though to a rather less extent than the above, but repeated in the front, as well as the back uptake, is observable in the Plate of the boilers of the 'Singapore,' 470 H.P. The most extreme case, however, of this kind will be seen by referring to the Plate of the boilers of another Government steamer, the 'Samson,' 450 H.P. These boilers, like those of the 'Singapore,' are also faulty in the back uptake; and in the front uptake, or chimney breast, to a monstrous extent, though both sets of boilers possess other qualities of a meritorious kind; but, unlike those in the 'Basilisk,' great strength is certainly not one of those qualities.

subject to be extremely dirty than other vessels ; in fact, it is periodical every sixth or seventh day on foreign service, and sometimes oftener, to be completely covered with coal-dust in every part exposed. Water is, and can never be entirely prevented from being, thrown over every part of the ship : it is this, and the every-day work of dashing water over the decks, that achieves the destruction of the parts above mentioned, more than any other cause ; the rain and spray certainly assist. Hence too much care cannot be taken in rendering every part of the deck, or other covering of the boilers, as tight as possible. Waste and feed pipes rather interfere ; but they can be, and are generally, now fitted beneath the deck, so as to be entirely out of the way of accident, in case the funnel be carried away.

The AIR CASING around the base of the funnel, in most vessels in Her Majesty's service, has been surmounted by a hood, water-tight, so as to prevent the water passing in that direction completely, the flanch of the casing being made tight on deck ; and the bottom cants of the coal-boxes are fixed two or three inches clear of the sides of the boilers, so as to permit dirt, which may not be intercepted by the pieces of wood, fitted between the crown and the coal-boxes fore and aft for that purpose, to be washed into the ship's bottom, whence it can be removed, thus preventing its accumulation between the coal-boxes and the boiler sides. If it could be afforded, sufficient space should be allowed for a passage around the boilers, by which they may be kept perfectly clean.

As little wood as possible should be used around the upper parts of boilers, in addition to the covering of the deck. Thin sheet iron, properly riveted and chinned, should take the place of comings, &c., which, with the carlines which support them, are frequently set on fire. Coals and wood, *not* directly in contact with the air casing, have often been fired in a very short space of time *on deck* when exposed, as likewise when contained in bags in the same situation. More than one air casing should invariably be fitted around the funnels of sea-going steam vessels, the air freely passing between them, so as not only to remove the risk of fire, in a great measure, but also the oppressive heat which is experienced in still weather in warm climates, when passing or standing in the neighbourhood of the same. The outer casing, whenever the construction of boiler will permit, should have a large flanch fitted *on deck*, which should be cut round as far as possible from the casing, the flanch being made perfectly tight, which can never be attained by the pitch and oakum joints of comings, or the hatches or platforms they support. Corrugated iron is a neat substitute for wood to surround the parts of boilers projecting above the decks, in vessels which cannot conceal them beneath ; but when the deck is sufficiently above the boilers, projections of hatches and scuttles should be avoided, the deck being more easily kept tight by being often wet, and occasionally caulked.

WATER-WAYS of marine boilers, to economize space, are often made much too narrow ; so that the crust, in falling from the sides of the flues, is intercepted with other matters left in the boilers by oversight or neglect; thus forming convenient shelves on which the calcareous matters repose and continue to accumulate. It is then inevitable that the side plates will be 'drawn' or bent towards each other by the fire, in its passage through the flues : not unfrequently, in such cases, the flues are so obstructed as to become impassable. The fire in its zig-zag course now attacks the bends or extremities of water-ways, which turn its direction into the joining flues ; cracks and openings are soon made, through which the water and non-conductors are forced ; in these places, patches are with difficulty fitted, and, from their situation, are exposed to be speedily injured from the increase of mass. Water-ways in no instance should be less than four or five inches wide, and in those between the fire-places something more ; the ebullition being so rapid here, that the water is more likely to be repelled, and the plates exposed to injury, which a sufficient quantity of water would obviate to a certain extent. If it be found convenient to make the spaces six, seven, or even eight inches, which is more than necessary in the largest boilers, no increased expense of fuel will be felt in practice, after the bulk of water is once heated : this fact is quite established.¹ Too much space beneath the

¹ Generally to increase the width of the water spaces between the furnaces will be advised by every engineer of sound judgment. The advantages of doing so are incalculable in many respects, but these advantages are too commonly sacrificed for the purpose of gaining a few more inches in width of heating surface and in width of fire-grate : for the last-mentioned purpose, the objection to large water-ways is a valid one, but the first is of little force. The way, however, I have always advised, is to meet both these objections together, by widening only the upper part of the water-ways, making them at least two inches wider at the top of the furnace or flue than at the level of the fire-bars, which ought to remain not less than six inches from inside to inside of furnaces. By this alteration at the top of the flue or furnace, making each of the sides incline one or two inches inwards, though lessened in quantity, the heating surface is always wonderfully improved in quality for generating steam.

Good examples of the kind of construction I am recommending are not often to be met with, and there is not one of the kind, with *flat-sided* furnaces inclined to the fire, among the whole of the Plates selected to illustrate this Paper. The Plate, however, of the circular boilers of the 'HYDRA,' 220 H. P., by Penn, having five circular furnaces in two tiers, shows an excellent method of arriving at a similar result. Here is a large area of direct fire, or radiant heating surface, with free escape for the steam. There is scarcely an alteration that could be suggested as an improvement in this boiler, unless that a little more space might be allowed in the first or cross flue, where all the five furnaces discharge their fire against the side plates opposite : this side, instead of being vertical, ought to be made to incline forward towards the fire some four or five inches, in accordance with the principles contended for in the two previous notes. With this alteration, and the three upper fires supplied by some simple fire-feeding apparatus, this excellent form of boiler, so well calculated for high pressures, would then also be rendered smokeless. Two good examples of this class of multiflue circular boilers are represented in two Plates, one containing a set of boilers for H. M. S. 'UNDINE,' 110 H. P., the other also for H. M. mail packet 'UNDINE,' 100 H. P., designed and executed by Messrs. Miller, Ravenhill, and Co. in 1849. They are

flues, in the lower class of vessels having little depth of hold, is not necessary; it takes away from the room above, requisite for scaling, and adds to the gross weight unnecessarily, by the increased stowage of water. A rectangular trunk or trough, extending the entire length of the bottom of each boiler, with a man-hole at both ends, is the plan most desirable; and being fitted between the sleepers, it descends beneath the other portion of the bottom, and becomes a receptacle for all the scales which may fall from the tubes. From the bottoms of these trunks the blow-off pipes, well protected by a grating, should proceed: thus the necessary space is gained, without too great an increase of weight or height.

Boilers that have been much incrustated, and the water-ways in many places choked, have in some instances, when blowing off could at all be effected, been perfectly clear beneath the flues; that is, the scales have not combined into a mass: therefore the space in addition to the trunk need not be much more than that pointed out for the water-ways between the flues, except in large vessels, where a space beneath the entire bottom of the flues is desirable for repair; and for the purpose of affording means of keeping the bottom of the shell perfectly *dry* when not employed,—a very necessary precaution on a foreign station. The accumulation between the tubes is much to be guarded against; to meet which a sufficient number of man-holes should be cut through the upper parts of the boilers, so as to permit a due ventilation for the men employed in scaling the boilers, which is greatly assisted by keeping the safety-valves open, (a material object in a warm climate,) as well as to afford convenience of repairing fire-places, and removing the scale, which I am persuaded has been often negligently permitted to fall between the tubes, by the people employed in scaling, to avoid the increased labour imposed by neglect of proper arrangements for removing the same, it not being at all times in the power of engineers to look after them: much time will be gained, as well in repairs as in cleaning, by anticipating these difficulties.

The great preparation necessary for cleaning and scaling a boiler, and the number of hands required to attend with buckets, &c. to remove the crust, frequently prevent an engineer from entering willingly on the task, unless he can calculate on sufficient time for the same; it is in proportion to the convenience afforded that these duties may be expected to be fulfilled.

substantially the same, containing perhaps an unnecessarily great amount of tube surface; but the sides of the furnaces are well arranged for durability as well as for generating steam; as was proved on their first trial.

An exceedingly well-arranged set of copper boilers are shown in the Plate of those for the 'SANS-PAREIL,' 350 H.P., by Messrs. James Watt and Co., having five elliptical furnaces, in which the principles governing the position of the heating surface are well observed, and where the most is made by the great diameter, nearly 10 feet, that the material will perhaps admit of.

FLUES need never be wider than to allow convenience for repair and sweeping, without reference to the magnitude of the boiler, so that much gain may be obtained in heated surface in large boilers by the introduction of an additional flue, when the breadth will permit; that is, the increased horizontal surface due to the dimension of a boiler for large engines over that of smaller ones will, with nearly the same water-ways, afford sufficient space for the flue as above, instead of increasing the width of the others to occupy the said space; thus the surface of two additional sides is gained for steam generation. Fifteen or sixteen inches may be taken as a good standard for width: it ought not to be much less, and need not be much greater.

30. As the safety of boilers must always be intrusted to the engineers, whose duty requires them to blow off a part of the water therein contained every two hours, it has often occurred, that from neglect, or from having their attention suddenly withdrawn from this momentous operation, the water has been allowed to descend below the flues and fire-places;—this, though rarely, might happen from a defect in the feeding pump or some of its apparatus: the burning of fire-places and flues is inevitable, and almost immediate, *no notice being given till the injury is effected*; and much greater mischief might take place, under the circumstances, from explosion even, when the water of the feeding pump is violently repelled, and flashed into steam of a high degree of expansibility, by the red-hot metal on which it is injected. The above neglect, and its partial consequences, *I have witnessed several times*; and it will and must be expected to occur again unless some arrangement is made, in order that the blow-off cocks or valves shall be closed, and the blowing off cease, when the water has descended to a certain limit consistent with the safety of the flues. In fact, I have considered blowing off, at all times, so important and dangerous an operation, that I never permitted it to be performed without the attendance of one fire-man at least, with the engineer of the watch, whose undivided attention was directed to trying the gauges, till the moment prescribed for shutting the cocks: so valuable a part of the machine as the boiler should not be left entirely to the discretion of men who may or may not look properly after it.

A 'DETECTOR PIPE,' as now fitted in some of Her Majesty's steam vessels, will effectually give notice of the approach of danger, in case the water is allowed to become low, as well as in cases where the action of the safety-valves becomes obstructed from any cause whatever, of which we have had some alarming instances. This pipe is bent like a syphon; one leg of which, two inches in diameter, to avoid becoming foul, descends beneath the water of the boilers to a point above the flues, where they are perfectly safe. From the bend, the height of which should be above that due to the pressure of steam in the boilers, a smaller leg

descends to the engine-room; the bottom being directed towards the ash-holes, with stop-cocks at hand, to be used when the boilers are entirely blown off on arrival, and so arranged that the cocks must always be open when the levers or spanners are removed. A hole is made, or a tube inserted, in the upper part of the bend, so as to prevent the 'detector,' on the inclination of the ship, or otherwise, from acting as a syphon. The steam rushing violently through the apertures into the engine-room, when the water is below the mouth of the pipe, will not only arouse the attention of those below, but will alarm the people who are at all times on watch on deck: there could then be no false account of the neglect, which would thus be publicly made known. Time will thus be afforded either to shut the valves or cocks, or to haul out the fires, when the boilers will be safe.

Instances have often occurred of cocks being re-opened by the engineer instead of shut: now in vessels as fitted by some engineers, cocks may be shut when turned half-round, and by others, with the common two-way cocks, which are shut only when turned one-quarter of a circle; thus, by force of habit, a person may inadvertently, in a strange vessel, re-open instead of shut a cock, and think all secure; it is the work of a moment, and this I have seen take place.

Mr. Kingston, by a very simple contrivance applicable to any of the ordinary blow-off cocks, entirely prevents this occurrence. A fork, or two horns, are fitted to the bottom of the common socket-spanner, which project so as to meet the pipe or shell of the cock, when it *must* be either open or shut, an opening of the figure of the socket and its horns being made in a plate which covers the cock, for that purpose. When the cock is open, the horns are beneath the plate, and of course the spanner cannot be withdrawn; so that a general order being given by the chief engineer to every person connected with the engine-room, that the spanner is on no account to be left in its place, it is clear that any one removing it must leave the boilers safe; and its situation being generally in the middle of the stoke-hole, if an engineer's attention by day or night should happen to be called off, a fire-man will, on observing it, be aware that all is not right, and will act accordingly. By adopting these precautions, which should be general in sea-going vessels, and are attainable at little cost, accidents which they are immediately intended to ward off will rarely be heard of; they scarcely could occur without the grossest neglect under such arrangements.

Glass water-gauges are useful, to show by inspection the height of the water in the boilers; but unless treated with great care, they will get out of order, and cease to be of service. *Copper floats* are much to be recommended, with an index to each appearing in the front of the boilers, the oscillation of which can be well observed night and day by every one below, and generally from the deck as well: floats seldom get out of order if properly made and attended to. Many boilers

have owed their safety to the timely warning of the floats when feeding pumps have ceased to act, and I am not acquainted with any real practical objection to their general use. I have known the feed to be regulated for days together, *at sea*, by floats, with great nicety: but this office I should not recommend, the levers requiring to be adjusted according to the varying state of the weather and speed of the engines. These ostensible indicators of the quantity of water in the boilers should be fitted to every vessel without exception; their just performance depends entirely on the care of the engineers.

Reverse valves, for the admission of air into the boilers when the vapour has less force than the atmospheric pressure, should never be less than four inches in diameter, and should be carefully cleaned and set in order prior to each voyage; as (for they are rarely tight) the dirt and salt congeal around the spindles and gear to such an extent as to soon render them useless in case of need: I have never seen them act spontaneously, even when the steam-gauge has been an inch below zero; and recent injury, to a great extent, by the collapsing of a boiler from this inefficiency of the valves, points out the necessity of observing the above precautions strictly, and not of *fixing* them to their places, which has been done occasionally, to avoid the nuisance of leakage, by those not duly estimating their probable utility.

31. Ultimately, the *fixing of boilers* in their places requires particular attention, the bottoms often giving out before any other part of the shell. All copper bolts, securing the sleepers to the ship's bottom, should be clenched beneath the surface of the sleepers, and then covered with wood let in flush with the same: or plank may be brought on each of the sleepers, when fixed of the entire length of boilers, and secured with iron nails; for, if a copper bolt-head comes in contact with any part of the bottom of an iron boiler, a hole will inevitably be eaten through in a short time in that spot, the most difficult of any to be repaired in place.

When the angle-iron projects beyond the bottom of the boiler, in the manner of Messrs. Boulton and Watt, it is customary to fill the space enclosed, with wood nicely fitted and coated with white-lead; so that, when in place, the bottom is well supported and protected from corrosion: but this method does not so well apply to other constructions of boiler; in bedding which, platforms laid across the sleepers should cautiously be employed. If a leak should exist in *any* part of the bottom, which is almost certain, the water, not being able to make its escape, flows beneath the bottom of the boilers, covering the surface of the platform, which supports them at the seams or stays only: this water is imbibed by the wood, which is thereby speedily rotted, the salt remaining in contact with the boilers, to effect their destruction. Boilers then, when not too near the bottom, may rest on the sleepers only, which should be thickly covered with some anti-corrosive, such as white and red

lead; and when fixed in their proper places, some one should be sent beneath, to fill up spaces in such parts as the irregularity of the bottom has prevented from coming in contact. The vapour arising from the bilge-water does not at all affect the parts of the bottom exposed to its influence. Boilers that have been in use for some years, placed as above, (the application of red-lead excepted,) have, when taken out, been found decayed in such parts of the bottom only as *rested on the sleepers*, with the exception of a few defects arising from bad workmanship or straining; the common lead-coloured paint remaining on the *plates exposed*, as when first applied by the manufacturer. But when the boilers by necessity are placed too near the wash of the bilge-water, their bottoms, which are soon covered entirely with salt, are rapidly and completely decayed; here platforms well covered with white and red lead must be resorted to.

32. The most important parts of marine boilers, and those on which opinions have not generally agreed, having been considered from the facts apparent on a strict examination of their details, when employed, and when totally dismembered after service, I have to observe, that if the boilers be constructed distinctly from each other, or so as to permit each series of flues to act on distinct bulks of water, the steam of each being under control, they will not only have all the advantages before described, but, as the efficiency of our steam marine is of paramount importance, and steam vessels are essentially ships, and liable to encounter the thousand casualties to which all ships are exposed,—a shot through one boiler would then by no means, after the escape of steam or water, prevent a vessel from continuing her way from an enemy, in the case of a merchant-ship; and if a steam frigate, there would still be an opportunity afforded to manœuvre, while a single shot meeting boilers which are not distinct would leave the ship a certain prize to the enemy. These considerations are not trifling, when it is recollected that steam vessels have already been extensively engaged for warfaring purposes in Portugal, Spain, and elsewhere; and although no shot has yet penetrated a boiler, the paddle-boxes and other parts have borne strong testimony of the risk to which they are liable.

The increase of expense to effect all suggested, is not worth mentioning as an item in the value of a steam engine.

To illustrate the construction of marine boilers, those of the 'Medea' and 'African' steam ships are represented in Plates XXII. and XXIII.

REMARKS ON ATLANTIC STEAM NAVIGATION.

33. In Atlantic steam navigation the fullest effect should be brought out with the engines and boilers as now constructed, the necessities being greater than that of any other effort of steam as a propeller.

WASTE OF FUEL FROM CYLINDERS.—I have alluded to the advantages of non-conductors; this should be carried as far as possible in these ships. Cylinders, slide casings, as well as boilers, should be completely encased. The following facts will remove all question of the propriety.

In the 'African' the cylinders are about 5 feet 3 inches distant from the boilers: there are no hatches *immediately* over them, and the short steam-pipes are covered with fear-nought, &c. The quantity of distilled water produced from the belts of 50 feet square surface which girt the cylinders (there are no jackets surrounding them) in the Mediterranean, was constantly about 270 gallons in 24 hours; that is, a quantity of fuel was lost by radiation from the belts of the cylinders in 24 hours, equal to that which would raise 270 gallons of water, at a boiling temperature, into steam. The steam-pipes, although covered, no doubt contributed in some measure to this loss.

From experiments made on board the 'African' in December 1831, moored in still water, without the influence of tides, 306 cubic feet of fresh water (measured) were required to maintain the engines at an uniform velocity of 12 revolutions per minute for 6 hours, at an expense of 24 cwt. of Heaton Main coal; one boiler or two furnaces only being employed; a certain portion of heat being abstracted by the joining boiler, which was in all respects distinct from that employed: now 270 gallons = about 44 cubic feet of water produced in 24 hours from the belts of the cylinders; and $306 \text{ cubic feet} \times 4 = 1224 \text{ cubic feet}$ of water evaporated in 24 hours by 24 cwt. $\times 4 = 96 \text{ cwt.}$ of coals, according to the experiment above noted.

$$\text{Hence } \frac{96 \text{ cwt.} \times 44 \text{ cubic feet}}{1224 \text{ cubic feet}} = 3.45 \text{ cwt. of coals as a dead waste,}$$

required in 24 hours to maintain the temperature of the belts alone.

Here the tops and other portions of two cylinders of 38 inches in diameter only, and slide casings, are not at all taken into consideration. The loss here recorded is rather under than over rated. The water thus procured was constantly appropriated to the use of passengers and the ship's company; and, when on the Alexandrian station, *no other* water was made use of in the ship, 10 tons only excepted, being the greatest quantity received at Malta, the absence from which port being never less than 18 days.

In the steam frigates, the quantity of distilled water produced at sea in 24 hours, by the jackets of the cylinders, of 162 feet square surface, amounts to upwards of 4 tons ! equal to 143·36 cubic feet.

Now, according to the foregoing,

$$\frac{143\cdot36 \text{ cubic feet} \times 96 \text{ cwt.}}{1224 \text{ cubic feet}} = 11\cdot24 \text{ cwt. of coals in 24 hours, to meet the radiation}$$
of heat from the jackets of the cylinders ; and when they are placed forward, and at a considerable distance from the boilers, the expense is much greater.

The saving of fuel and comfort in the engine-room would be, on the whole, very considerable, particularly in 400-horse engines, were the loss, before estimated, prevented by clothing.

34. WASTE OF HEAT FROM BOILER.—As to the waste of heat from the boilers, from experiments I made in the coal-boxes, I found that when the thermometer ranged from 50° to 59° on deck during five days, it increased to 116° in the boxes, the thermometer being suspended from the beams in the neighbourhood of scuttles which were left open more or less night and day, and through which the heated air was constantly escaping from the coal-boxes : this heat was radiated through a space of 6 or 7 inches, at which the coal-boxes were distant from the boilers, a large hatch directly over the boilers being at the same time kept open for ventilation. The thermometer, when the bulb was applied to the coal-box plates, two-thirds of their depth from the deck, varied from 138° to 148° ; and when applied to the front plates of the boilers, the temperature indicated was 169°, not very greatly exceeding that of the coal-box plates.

One important fact was elicited on these experiments, that when the surface of the coals was removed, and the thermometer introduced amongst the lower portion, it was raised 36° above the temperature of the air in the boxes, vapour being given out from the surface exposed ; that coal which was immediately in contact with the coal-box plates appearing as if dry distilled. From this I was led to judge that the lower portion of the coal being pressed upon by the superincumbent mass, and constantly receiving heat from the moment of getting the steam up, maintained this heat embodied in the form of vapour ; which, not being able to escape through the mass, assisted in extracting the gaseous portion of the coal, tending to produce spontaneous combustion ; which I have witnessed in several instances, although these consequences are mostly found to be brought about by defective smoke-joints. The injurious effect of this heat on the constitution of the coal-trimmers, and the great amount of fuel wasted by this channel, clearly demand every attention from those interested in the Atlantic voyage.

From the data furnished by the loss of fuel from the jackets of the cylinders, all other circumstances being the same, an approximation may be arrived at of the

waste by radiation from the boilers ; thus the entire external surface of the boilers and steam-chests of the 'African' amounts to 855 feet square ; and the area of the belts being 50 feet square, effecting a loss of 3.45 cwt. of coals per day, we have

$$\frac{3.45 \text{ cwt.} \times 855 \text{ square feet}}{50 \text{ square feet}} = 58.99 \text{ cwt., or } 2.95 \text{ tons of coals required in 24 hours}$$

to meet the loss from radiation in these comparatively small boilers : in this calculation the surface of the bottom of the boilers is included ; the loss from which, it should be observed, is trifling when shielded by platforms from exposure to the bilge-water.

The boilers, on the whole, are certainly less exposed than the cylinders, but, from their greatly reduced thickness, they transmit the heat more readily.

When one boiler only is employed, the side next its neighbour, by giving out heat thereto, is another source of loss. The side of either of the 'African's' boilers has 123 feet square surface. Then, as before,

$$\frac{3.45 \text{ cwt.} \times 123 \text{ square feet}}{50 \text{ square feet}} = 8.48 \text{ cwt.}$$

of coals expended in maintaining the temperature of the contiguous boiler. I think this falls short of the actual waste by this channel in 24 hours.

'Dee' steam-frigate, 200 horse-power ; area of jackets, 162 feet square ; external surface of boilers and steam-chests, 1783 square feet. Now the actual waste by her jackets per day,¹ as before estimated, is 11.24 cwt. of coals ; and

$$\frac{11.24 \text{ cwt.} \times 1783 \text{ square feet}}{162 \text{ square feet}} = 123.7 \text{ cwt., or } 6.18 \text{ tons of coals loss in 24 hours}$$

by radiation from the exposed surface of the boilers ; the surface of the bottoms being included.

Again, the area of the sides of one set of boilers opposed to their neighbours in the same vessel amounts to 263 feet square. And

$$\frac{11.24 \text{ cwt.} \times 263 \text{ sq. ft.}}{162 \text{ square feet}} = 18.25 \text{ cwt.}$$

of coals loss in 24 hours from absorption, when one set of boilers alone is employed. If the above is considered as a fair estimate of the loss from radiation in 200-horse vessels, it must of course be proportionally greater in vessels of double the power.

35. ECONOMY IN THE EXPENDITURE OF COALS.—In order to obtain a correct idea of the number of days' fuel which a vessel can carry, an important consideration in vessels of long voyage, it should be estimated what amount the boilers consume at full speed in still water, (the greatest expenditure takes place under these circumstances,) making allowances for clearing out fires alternately, after having been some time under weigh : under every other circumstance the consumption is rather less than greater. During strong gales the consumption may be very considerably reduced : I have seen seven days' fuel protracted to

¹ The steam-pipes were clothed.

eleven, by working such of the furnaces only as were adequate to the wants of the engines.

I subjoin one or two extracts from my journal of a Mediterranean voyage, which will show, to a certain extent, the advantages of this practice, labouring under the drawbacks of radiation before detailed.

1st Experiment. 10 hours with Welsh coal. Consumption, $9\frac{1}{2}$ bushels per hour with 4 fires. Revolutions, 25 per minute. Speed of vessel, 7 knots per hour by log. Vessel deep; smooth water.

2nd. Strong winds ahead. Put out one fire, and close the furnace mouth. Consumption, 8 bushels per hour with 3 fires. Revolutions, $18\frac{1}{2}$ per minute. Speed of vessel, 5 knots.

3rd. Strong gales ahead. 2 furnaces, or one boiler only employed (being robbed now by that in disuse). Consumption, 6 bushels per hour. Revolutions, 11 per minute. Speed of vessel, 4 knots.

These extracts of actual work will give the best idea of what might be further gained by a better arrangement than sea-going steam vessels are usually prepared with.

36. SWEEPING FLUES, &c.—Persons not practically acquainted with the working of marine boilers on long voyages are liable to form erroneous notions of the accumulation of soot and its consequences. In the first place, soot cannot exist in the furnaces when the plates of which they are formed, with the best management, are constantly giving out from the intense heat they sustain. The accumulation in the flues is principally on the bottoms, as will presently be shown. The chimney or funnel never *absolutely* requires to be swept, even in the worst cases of draught. In some vessels the practice is resorted to simply as a matter of course: in the 'African' it was *never* done, except to prevent the dust from falling on those repairing the flues immediately beneath, when it was previously beaten only on the outside for that purpose: again, the vessels in the Mediterranean packet service are never detained on their voyage of 1000 miles, no matter how long the time occupied thereon, to sweep the flues.

The 'African' some years since, when in the colonial service, made the passage from England to Malta direct, nearly 2000 miles. On the third day after her departure a fair wind sprang up, the wheels were unconnected, and the vessel put under canvas: it was thought a favourable opportunity of setting the machinery in order; the flues were swept at the same time, in order to profit by any advantage arising therefrom: after having sailed two days, they proceeded by steam at full power and fine weather for the nine succeeding days, at the end of which time no lack of steam was apparent. After this she went from Malta to Alexandria, 820 miles,—thence to Beyrout, 320 miles,—back to Alexandria, and thence

to Malta, without sweeping the flues,—a distance of 2200 miles ; the necessity of arriving at Malta with the Indian mails preventing the vessel from remaining a sufficient time at either of the posts for the purpose of sweeping the flues.

The sweeping of the flues consists simply in removing the soot and burnt fuel carried over by the draught from the lower part of the flues ; the upper portions, which are available for steam generation, having merely a thin coating of soot, which by no means amounts to a formidable non-conductor.

After the long voyage of the 'African' above alluded to, I was curious to know the condition of the flues, more particularly as the steam was generated in abundance, without any apparent increase either of labour or fuel, immediately before arrival ; a blue lambent flame (carbonic oxide) constantly appearing some feet above the chimney, as was usual after being a day or two under weigh : it appeared that the flame had reverberated downwards, so as to act on the lower parts of the first or main flue of each boiler : the soot was deposited on the bottoms of the other flues to a greater extent ; and beneath the chimney, the soot was swept, so as to leave an opening about one foot clear, out of 4 feet 6 inches, the entire depth of flue ; the voyage having occupied, with stoppages at Alexandria and Beyrout, about twenty days.

Shortly afterwards a voyage was made from Malta to Corfú, of between four and five days ; the flues were then swept, and, to my surprise, as much soot was withdrawn as on the occasion last described : it then became quite evident, that after a certain quantity of fine cinder and soot had been carried over and deposited, the surface, being swept by the flame and heated air, was rendered so light as to be carried up the chimney, and driven away at the same rate as its formation ; and this conclusion was confirmed by the quantity of burnt soot which was strewed over the decks, at night in particular, after the awnings were furled, being sensibly crushed by the feet on pacing the decks. Again, having examined the flues of the same vessel, after being employed on experiments, &c. for twenty-five days, during the months of June and July 1837, (coals used principally, West Hartley,) the steam was generated abundantly at the conclusion, and the flues contained far less soot than I had calculated, which I attribute to less urgent firing : the sides and tops of the interior of the flues were comparatively clean. From this it may be inferred, that were sufficient coals on board, a vessel with boilers of *good construction* might continue to steam for an indefinite time or distance, so far as the accumulation of soot is concerned. It should be observed, that the coal employed in the two former cases was not all Welsh coal ; a quantity of Newcastle and Beyrout coal having been procured at Alexandria.

The flues of marine boilers are rarely on fire ; I never saw but one instance, when the ignited soot was carried through the chimney in a shower which lasted

nearly an hour, on board a merchant steam vessel which had only made the voyage from Ireland to St. Andero, and back to Falmouth. I have questioned several engineers of long experience at sea, who have never witnessed any other appearance than that which is common to all steam vessels after being some days at sea; viz. the flame of carbonic oxide flickering at the top of the chimney, and perceived only at night. The burning of a vast quantity of smoke, and its consequent soot, is to be referred to the great admixture with the air introduced through the fire-doors during the operation of feeding: this has been often exemplified by leaving the doors slightly a-jar, when the smoke is most completely consumed.

37. FRESH WATER.—Charging ordinary boilers with fresh water, prior to starting for a long voyage, is certainly to be recommended; it cannot be too frequently done, if at no very great expense and labour of a ship's company. I think, however, its advantages have been generally too highly rated: it was rarely done in the 'African;' but from its probable tendency to loosen scale, as well as to prevent the formation of the same to a certain extent, till totally displaced by the salt water, it has its advantages.

From experiments before detailed, the engines of the 'African' were maintained at twelve revolutions per minute, with an evaporation of 306 cubic feet of fresh water in six hours, by two furnaces, or one boiler, a certain portion of heat being abstracted by the adjoining boiler: now with both boilers in use, the engines are abundantly supplied with steam at twenty-eight or thirty revolutions, a surplus flying to waste; so that we may reckon that at all times double the above quantity will be evaporated with both boilers.

That is, $306 \text{ cubic feet} \times 2 \text{ boilers} = 612 \text{ cubic feet evaporated in 6 hours}$; and $612 \times 4 = 2448 \text{ cubic feet} = 68.3 \text{ tons of fresh water required in 24 hours}$ to meet the necessities of the engines at full speed; and this is more than treble the contents of both boilers when charged: so that during twenty-four hours the fresh water will have been displaced by more than treble its quantity of salt water: therefore the advantages of fresh water are limited, and a boiler may keep at sea for a considerable time, exclusive of accident, depending alone on the system of change usually adopted in vessels of long voyage.

Hence the only question of a vessel's continuance at sea, for any consistent period of time, is—the fitness of the engines,—the conduct of the boilers,—and the quantity of fuel which she can stow, compared with her consumption. Consequently the probable capacity of a steam vessel for the Atlantic or any other voyage, so far as her machinery is concerned, may be fairly estimated before she finally sets out for her destination; the contingencies of weather on the particular service being duly considered.

ADDITIONAL NOTES.

HAVING been called on at a short notice to revise the foregoing reprint of my friend Mr. Dinnen's valuable Paper on Marine Boilers, it was with considerable hesitation that I responded to it; and not at all until after my entire conviction of the impossibility of the author being relieved from any portion of his numerous and onerous official duties,—or sufficiently so to enable him to execute the task himself, in the time required to satisfy the most patient of the numerous readers of this work. Those on the Continent of Europe and in the United States of America, to say nothing of our great Australian and other Colonies, exhibit an eagerness to be informed of everything relating to the steam engine. Under these circumstances, the observations I have felt it necessary to make naturally take the place of foot-notes, and are generally such as I had partially prepared for Mr. Dinnen's use. Although I regret that these notes necessarily go forth without the stamp of either his authority or correction,—for it is a fact that Mr. Dinnen has had neither time nor opportunity to look at any of the preceding pages before they are issued to the public,—yet the circumstance will not perhaps be entirely without its use, in so far as it will be certain that the opinions expressed by both author and editor are equally uninfluenced by official considerations,—R. A.

NOTE A.

The question of the best boiler is still the great problem of Marine Engineering, notwithstanding the strongly expressed opinions of the first practical authorities of the day that it is a very simple affair. That a good boiler ought to be simple is admitted, but the difficulty is how to make it so while the strong conservative prejudices of the old school of mechanics remain, with their inveterate attachment to *larger heating surface*, which cannot be had without great weight of metal,—*slower combustion*, which is impossible without greater space,—*smoke combustion*,—*perfect combustion*,—&c., &c. To remove these prejudices effectually, little short of another revolution in steam navigation is required for stirring up the stagnant tendencies that are creeping over engineering, similar to what occurred at the period of the introduction of the present railway system. It is entirely to the locomotive that the steam vessel is indebted for the present 'multitubular' boiler, although, had a mind of equal originality and energy to the Father of Railways presided over the destinies of Steam Navigation, it is probable that a less servile copy would have been adopted.

A great and decided improvement has been made in the speed of steam vessels since the general substitution of the 'tubular' for the 'flue' boiler. It is not, however, so much to the tubes as *heating surface*, but to their capability of bearing pressure, that this speed is owing. On this account the present form of marine boiler requires little to remark on, it being, with the exception of the blast-pipe, essentially the locomotive boiler. For all the details of its manufacture, therefore, it is impossible to refer to better authority than the various Papers and Plates contained in the first Division (A) of this work,—at present only directing attention to the Plates engraved to accompany Mr. Dinnen's Paper.

Plate LXVIII.

REFRIGERATOR FEED AND BRINE PUMPS.

This is a modification of Maudslay and Field's brine-pump, described below, but with a 'refrigerator' attached, which is a box full of small tubes, exactly like a portion of Hall's patent condenser. This part of the apparatus is for *cooling* the brine. The hot brine being discharged through the box, imparts a portion of its heat to the enclosed pipes, and through them to the feed water, which is all passed through the small pipes for that purpose. A reference to the figures is engraved on the Plate.

Plate LXIX.

FEED AND BRINE APPARATUS, as fitted on board the West India Royal Mail Company's Ships.

This is Mr. Mill's arrangement for connecting the feed and brine valves, which, instead of having one spindle common to both, as in Seaward's apparatus, have each a separate spindle attached to the valves *c e*, and jointed to a common lever *d*. This lever has an adjustable fulcrum *f*, moveable by means of the long screw *h*, on a slotted frame, to which it can be fixed by a set-screw at any point required. It will be seen by varying the position of this fulcrum, that the stroke of the brine-valve relatively to that of the feed-valve can be readily adjusted in any proportion, so that more or less of the brine may be constantly extracted from the boiler. Though not quite so simple as Seaward's, this is as neat and compact an arrangement for the 'constant blow-off' as can well be devised.

Plate LXXIV.

SEAWARD'S PATENT BRINE AND FEED VALVES, adapted for a pair of Boilers of 200 horse collective power. Canal Iron Works, Poplar, 1850.

This apparatus is a simple and ingenious improvement on what is called the 'constant blow-off.' The valve *H*, for letting the brine out, is connected to the same spindle with the valve *D*, for admitting the feed water into the boiler. The area of these valves being in the proper ratio to each other, and acting simultaneously, no more brine escapes than is demanded by the evaporation. Instead of weights, as in the brine-pumps, the valves are kept to their seats by an adjustable spiral spring *G G*, and the discharge may be stopped or moderated at pleasure by the cock *M*, placed above the outlet-pipe *L*.

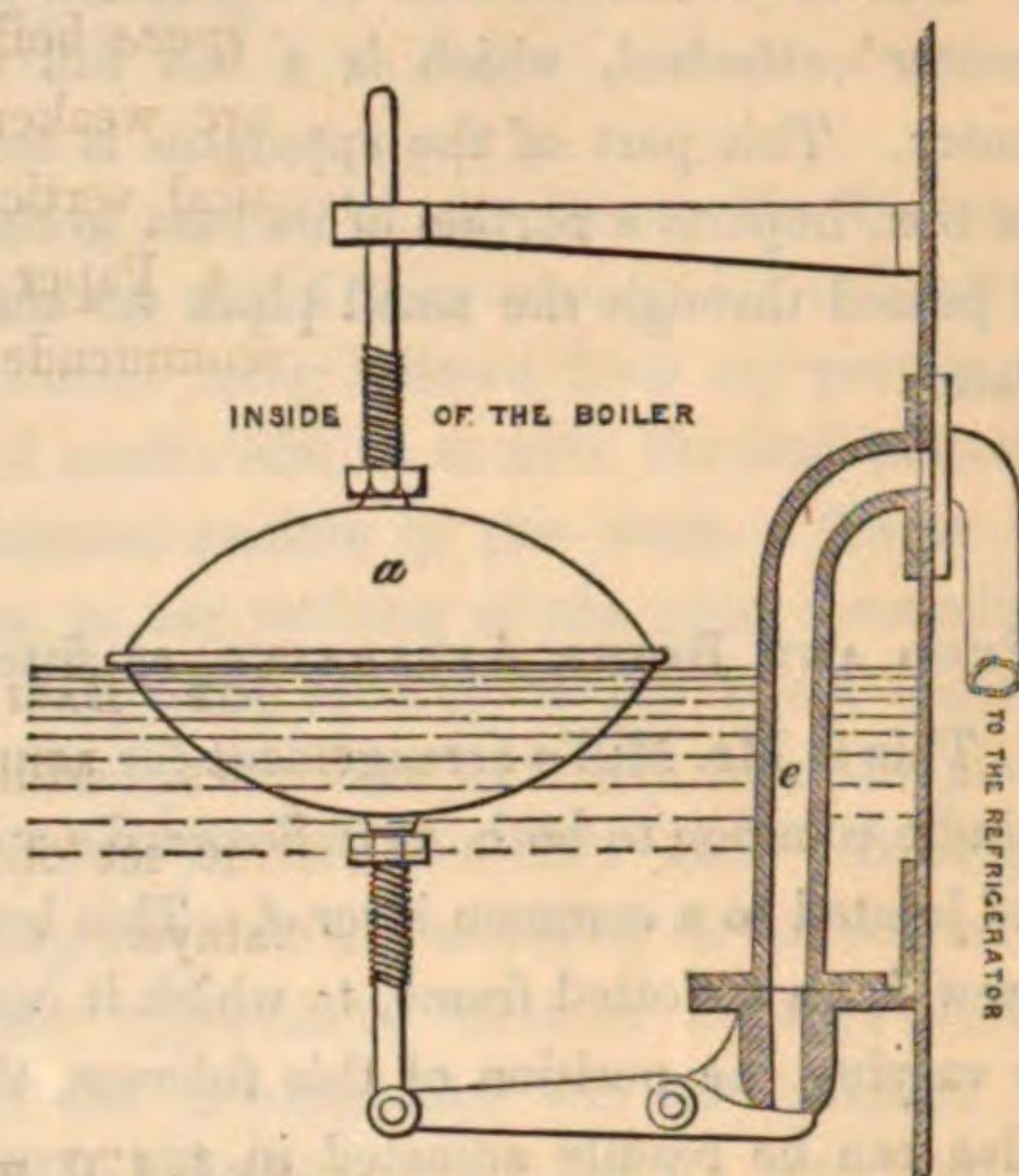
Plate LXXVIII.

BRINE-PUMPS, as fitted on board H.M.S. 'MEDEA.' 220 H. P. Maudslay, Sons, & Field.

The operation of these pumps is quite sufficiently described by Mr. Dinnen (art. 4, page 4). There are no letters of reference to the figures, but the two pumps are shown in elevation, marked 'End View,' on a scale of $1\frac{1}{2}$ inch to a foot: they are of the ordinary forcing species, with common conical valves; a vertical section of one with its valve-box and valves is shown in the left-hand corner, where is also seen the pump-rod in elevation and the mode of its connection by a bell-crank motion to a 'rod from the engine beam.' The exit-valve is loaded to a little above the pressure of the steam in the boiler by a weighted lever resting on its spindle, in order to prevent the brine being forced out when the pump is not at work. Now it will be observed, if in place of this we had a *stop-valve*, or a common sluice-cock, which is better, the brine could be easily discharged by hand in any required proportion, and all the rest of this expensive apparatus dispensed with. An arrangement of this kind is known as the 'constant blow-off.'

NOTE B.

A different kind of blow-off apparatus has been introduced into the boilers used by the Peninsular and Oriental Steam Navigation Company, by Mr. Lamb, their resident Engineer. It is represented in the figure, taken from 'Murray's Rudimentary Treatise,' in which it is called 'LAMB'S SURFACE BLOW-OFF APPARATUS,' and is described to consist in "blowing off partly from the *surface* in addition to the usual method from the bottom, by which means *many* of the particles of insoluble matter, of which the scale is formed, which are ballooned up to the surface on bubbles of steam, are caught and removed from the boiler before they have an opportunity of aggregating and falling to the bottom." So far as this description goes, it is that of my invention of the cleaning machine for marine boilers, two of which I made and *fixed* in a set of boilers for a vessel called the 'Phoenix,' at Scott, Sinclair, and Company's, Greenock, more than ten years ago, which were the first things of the kind seen in Scotland.



The above description of the operation of the 'surface blow-off' by Mr. Murray appears to be borrowed from Mr. Bourne, in whose 'Catechism of the Steam Engine' (answer to question 141, last edition) this *second-hand* 'contrivance' is called 'Lamb's scale preventer:' he also states that in practice it "is found to be very effectual." In this statement, however, there are one or two mistakes, which I presume to have arisen from the accidental mixing up of miscellaneous information from various quarters along with the papers and drawings supplied by me for the 'Artisan Club's Treatise on the Steam Engine,' in which work a similar passage occurs. Excepting some of the first few trials which were made in two of the City of Dublin Company's vessels, the 'Shamrock' and the 'Duchess of Kent,' some fourteen or fifteen years ago, the apparatus was never used with that view, that is, to prevent *scale*; and then it was but partially successful as respects the *carbonate* of lime; but with the worst species, the *sulphate* of lime, using the apparatus freely seemed to have the contrary effect of making the scale *harder*; so that the term 'scale preventer' is a misnomer.

The use of the 'boiler cleansers,' however, frequently (three or four times an hour) as a 'surface blow-off,' and occasionally as a 'constant blow-off,' was in every instance thoroughly effectual: in the first case removing the 'scum' from the surface of the water, whence they afterwards received the name of 'scum-cocks' and 'scum-pans,' thereby preventing priming; and in the last case superseding the necessity of using brine-pumps of any description, as well as preventing the necessity of periodical blowing off. Were I to conclude this note here, it would be doing injustice to those of my (North) countrymen who have *re-imported* and patented this 'contrivance' in England, as well as to my talented friend the author of the 'Catechism of the Steam Engine and Screw Propeller.' After the above-quoted description, and stating that it has been "*successfully introduced*" into the Company's boilers, Mr. Murray adds, "This apparatus *may be* made self-acting by means of a float, which, rising or falling in proportion to the amount of feed-water admitted, opens or closes the blow-off pipe."

Although this self-acting part was originally used by me in *land* boilers, I would not have reclaimed any portion of the invention, in this place, but for the purpose of disclaiming the application of the float, as both useless and dangerous, in a *marine* boiler. In place of a float I *fix* a sediment collector, or 'scum-pan,' by an adjustable attachment at the mean water level, and blow off through a sluice-cock on the front of the boiler by hand. A figure of my improved cleaning machine for *land* boilers is given at page 129 of this Division of Tredgold.

NOTE C.

The two sets of boilers in Plates LXXI. and LXXXV. are remarkable examples of causing the fire to pass *over*, or at the side, instead of *under* the water chambers; on which see foot-notes to pages 29 and 32. *Sheet-water space* boilers, as in the 'Singapore,' though in some respects superior to the common tubular kind, are weaker. The strongest kind of tubular boiler is Galloway's (see page 276, Division B,) with conical vertical *water* tubes. It is sufficient warrant for the strength of these boilers to state, that in a Paper recently read before the British Association at Belfast, Mr. Fairbairn of Manchester recommended and adopted the use of these conical water tubes mainly on that account.

Plate LXX.

BOILERS OF H. M. STEAM SLOOP 'BASILISK,' 400 H. P. Four separate boilers, set in pairs, before and abaft the engines. Miller, Ravenhill, & Co. See foot-note to page 32.

This is a drawing of the same set of boilers as in Plate LXXXIX., by the makers, showing the important details of rivets and stays.

Plate LXXI.

BOILERS OF THE 'SINGAPORE,' 470 H. P., belonging to the Peninsular and Oriental Company.

Messrs. Lamb & Summer's Patent. See foot-note to page 32.

This Plate contains sections of the boiler of the screw steamer 'Ann,' 50 H. P., one of the same patent 'sheet-water space' boilers as those in the 'Singapore.'

Plate LXXX.

BOILERS OF H. M. STEAM SHIP 'NIGER,' of the collective power of 400 horses. Fitted by Maudslay, Sons, & Field.

A drawing of the same boilers as in Plate LXXXVIII., by the makers, showing a 'reflector' or 'deflecting plate' for reverberating the flame, used in consuming smoke.

Plate LXXXIV.

BOILERS OF THE 'MINX' AND 'TEASER,' 100 H. P., transferred to the 'Wasp,' by Miller, Ravenhill, & Co. Calculation of surfaces, &c., on the Plate.

Plate LXXXV.

BOILERS OF THE 'SAMSON,' 450 H. P., made at Woolwich in 1849. See foot-note to page 32. Calculation of surfaces, &c., on the Plate.

Plate LXXXVII.

H. M. S. 'DESPERATE,' 400 H. P. Maudslay, Sons, & Field. Calculation of surfaces, &c., on the Plate.

Plate LXXXVIII.

H. M. S. 'NIGER,' 400 H. P. Maudslay, Sons, & Field. Calculation of surfaces, &c., on the Plate.

Plate LXXXIX.

H. M. S. 'BASILISK,' 401 H. P. Boilers four in number. Miller, Ravenhill, & Co. Calculation of surfaces, &c., on the Plate.

NOTE D.

The facts brought forward by Mr. Dinnen (in article 20 to 23), corroborative of the general superiority of copper to iron for marine boilers with *low-pressure* steam, were in strict accordance with my own experience at the time of their first publication, having previously had occasion to witness how rapidly the destruction of the internal fire-boxes of locomotives was effected, when of iron, as compared to those of copper; however good the material and workmanship of the former might be. Many of those facts indeed appeared, both to myself and others, much stronger than could be accounted for by the simple difference in the conducting power of the two metals, and this was the cause of their being examined into and substantiated with great care, before the use of copper, at so much greater first cost, could be justified in the early infancy of the railway system.

The results arising out of this investigation were generally of so coincident a nature with the facts observed by Mr. Dinnen, although the circumstances of the two cases were so widely different,—one being with salt water and low pressure, the other fresh water and high pressure, together with the destructive operation of the blast on a coke fire,—that I was induced to suspect the existence of some other operating cause common to both, besides the great conducting power of the copper. This coincidence of results, on further examination and experiment, was found to be entirely owing to the vertical position of the side plates of the furnaces.

Several suggestions and conclusions, for improvements in the design and construction of boilers, arose out of this discovery, which were imparted to, and acted upon by, more than one manufacturer of boilers with unvarying success. The results of this experience were also, at the request of a mutual friend, communicated to Mr. Dinnen, together with the following analytical *valuation*, if I may so call it, of the principle of substituting copper for iron in all cases where vertical heating surface *must* be used,—such as are the fire-boxes of locomotives; although in other cases, where space will admit, the same end is arrived at, with iron, by merely slightly *inclining the heating surface towards the fire*.

The *theory* of the subject is a physical problem of no little difficulty, and as the *practical* solution of it is already given and acted upon, I am not solicitous to parade any theoretical demonstration; but the following attempt at one may have its interest in this place, even if not admitted to be entirely satisfactory, until a better can be found.

Theory of the longitudinal conduction of heat through the vertical Furnace plates of Steam Boilers.

When heat is, from whatever cause, prevented or considerably impeded in passing transversely through the metal plate to the water, it will of course spread itself through the substance of the plate in a longitudinal or any other direction from the source of heat, which, in this case, as the lower edge is in contact with the burning fuel, must be generally upwards towards the crown of the furnace. Now the more rapidly this heat is conducted off towards the crown, the less likely is the metal to suffer injury from overheating. In the case of copper, which conducts heat 2·4 times quicker than iron, it would on a superficial view appear that it ought to be 2·4 times more durable.

It is, however, necessary in the first place to consider that the temperature of the crown plate, taken separately from the sides, must have a tendency to rise in some ratio inversely proportional to the rapidity with which the heat is transferred from the plate to the water, that is, *inversely as the conducting power of the metal of which it is composed*.

In the next place, we know that the heat imparted to the lower portion of the side plate by the burning fuel with which the latter is in *immediate contact*,—excepting only such small portion of it as may be transferred laterally,—must all be conducted longitudinally upwards by the metal of the side plate to that of the crown, in the ratio of some power of the difference of temperature between the crown and the sides,

—the temperature of the latter having a tendency to rise *inversely in this ratio*. Consequently, the total effect of the undue action of the fire against the side plate must be as the above two ratios conjointly.

For an algebraical expression of these ratios, let M represent the conducting power of any metal above another given standard, which call 1, T = the mean temperature of the side plate in contact with the burning fuel, t that of the crown plate, and put n = the index of some power of $T - t$, expressing the rate of cooling of a heated metal plate with its edge in contact with one of a lower temperature to be determined by experiment. Then the total effect of overheating the side plate may be expressed by

$$\frac{1}{M} \times \frac{1}{(T-t)^n} = \frac{1}{M(T-t)^n}$$

and the reciprocal of this will express the relative durability (d) of a side plate of iron, copper, or any other metal, of which we know its relative conducting power; or,

$$d = M(T-t)^n.$$

We may assume that the temperature of the crown plates, when of copper, is not perceptibly greater than that of the water above it, which for low-pressure steam from fresh water we may call 215° Fahr. or $t = 215$; and the temperature for iron will only be one or two degrees higher, according to the thickness of the metal and the perfection of its manufacture. We may also make T three or four degrees higher than t , say about 218° or 219° , or any other temperature which the copper may be able to bear, without immediate injury, on the supposition that only a certain limited and small amount of heat passes transversely through the side plate to the water or steam within. When the furnace is of iron, the temperature of the sides, *at the place of contact with the burning fuel* on the grate, will of course be the same as for copper, provided that all, or nearly all, the heat derived in that way is carried off by longitudinal conduction upwards in the same manner, though at different rates, by both metals,—or what amounts to the same thing, provided that the quantity of heat transmitted laterally is equal in each case.

Adopting the above data we shall have, for copper $d = 2.4(219-215)^n = 2.4(4)^n$,

$$\text{and for iron } \begin{cases} d = (219-216)^n = 3^n \\ d = (219-217)^n = 2^n \\ d = (219-218)^n = 1^n \end{cases}$$

accordingly as we assume the value of t for iron. Then if, for example's sake only, we assume $n = 2$, we have $2.4 \times 4^2 = 38.4$ to represent the durability of the copper, and the relative durability

$$\text{for iron } \begin{cases} d = 3^2 = 9 \\ d = 2^2 = 4 \\ d = 1^2 = 1 \end{cases}$$

Taking the medium of these results, or 4, which is to 38.4 as $1 : \frac{38.4}{4} = 9.6$, would make copper to be nearly ten times more durable than iron.

NOTE E.

The set of Boilers in Plate LXXXI. in the following list are conspicuous for originality of design and the possession of qualities calculated for efficiency and durability, in accordance with the principles developed in the preceding note. The two sets for the 'Undine,' 110 and 100 H.P., are the same pair, the discrepancy of 10 H.P. arising from the drawing of the former being made at Woolwich Dockyard, and that of the latter probably at Blackwall. See similar discrepancy in Plates LXX. and LXXXIX., Note C.

Plate LXVII.

DOUBLE-STORY BOILERS OF H.M.S. 'DEVASTATION,' 400 H.P. Maudslay & Field.

An inferior specimen of the old flue plan of boilers. See References on Plate.

Plate LXXII.

ORIGINAL DOUBLE-STORY BOILERS OF THE 'GREAT WESTERN.' Maudslay & Field.

As good an example of the old flue boiler as the plan admits of. See References on Plate.

Plate LXXIII.

TELESCOPIC CHIMNEY, OR SLIDING FUNNEL, OF H.M.S. 'HYDRA,' 220 H. P. Description on the Plate.

This is the invention of Mr. R. Taplin, of Woolwich Dockyard, who was deservedly rewarded for it by the Exhibition Medal of 1851.

Plate LXXV.

BOILERS OF H.M. MAIL PACKET 'UNDINE,' 100 H. P. Miller, Ravenhill, & Co. See Notes to page 34. The same boilers as in Plate XC.

Drawing by the makers, containing details of rivets and stays.

Plate LXXIX.

PLAN OF THE FOUR BOILERS, with the supplementary Steam-chests and Shut-off Valves, as employed on board the 'AVENGER' STEAM FRIGATE. Seaward & Capel. See References on the Plate.

Plate LXXXI.

BOILERS OF THE 'HYDRA,' 220 H. P.

John Penn, Inventor. See foot-note to page 34. Calculation of surfaces, &c., on the Plate.

Plate LXXXII.

EXPERIMENTAL BOILER, WOOLWICH YARD, 50 H. P. Formerly in H.M.S. 'Lightning,' 100 H. P. Maudslay & Field. See Description on the Plate.

Plate LXXXIII.

BOILERS OF H.M.S. 'TERRIBLE,' 800 H. P. Four Boilers, of 200 horse-power each. Maudslay, Sons, & Field. 1851. See References on the Plate.

Plate LXXXVI.

DANIEL'S PYROMETER. Full size.

Plate XC.

H.M.S. 'UNDINE,' 110 H. P.

Miller, Ravenhill, & Co. See foot-note to page 34. See calculation and report of performance on Plate.

DESCRIPTION, WITH ILLUSTRATIONS,
OF
THE TURBINE WATER-WHEEL
CONSTRUCTED AND IN OPERATION

AT LOWELL, MASSACHUSETTS, UNITED STATES.

BY JAMES B. FRANCIS, C.E.

The following communication is intended to illustrate some recent and important improvements in the construction of the Turbine Wheel, as at present extensively adopted in the United States and on the Continent of Europe; and although the principles which are here developed may be deemed extraneous in a work devoted to the application of steam as a motive power, it is anticipated that a description of this newly constructed wheel may be usefully appended to the present edition, and obtain the concurrence of no inconsiderable portion of our numerous Subscribers.—J. W.

“Lowell, Massachusetts, November 17, 1851.”

“MY DEAR SIR,

“According to promise, I send you drawings of a large turbine water-wheel constructed here under my direction.

“The statement of the performance of this wheel may be considered as an exaggeration, but I can assure you that I have rather understated the results, from a conviction that the truth would be deemed almost incredible, unless supported by the testimony of others. If you desire to obtain additional information on the subject, I have much pleasure in referring you to Mr. Abbott Lawrence,* who has the three largest and most perfect turbines ever constructed in his manufactories at Lawrence, in Massachusetts; they are about 500 horse-power each, and were constructed from the designs and under the immediate superintendence of Mr. Boyden.

“The principal improvements introduced by Mr. Boyden into the turbines constructed by him are—First, the diffuser, by means of which the living force arising from the water having a velocity on leaving the wheel is rendered at least in part useful; it is accomplished in a manner somewhat analogous to the increased discharge of water through certain diverging orifices. The gain of useful effect from this improvement is found by experiment to be about 3 per cent.

“Secondly, the mode of suspending the wheel from the top of the shaft, by which

* The Minister of the United States, now resident in London.

contrivance the difficulty arising from the wearing down of the step is entirely avoided; the bearing, as constructed by Mr. Boyden, being always accessible, and as easily taken care of and prevented from wearing as any other bearing: it will be seen by reference to the plan that there is hardly any limit to the weight that may be safely borne by a bearing of this description, as a proportional surface can always be had by increasing the number of collars. It will probably be objected to this kind of bearing, that it is impossible to work so accurately as to make the collars take the weight uniformly; but this difficulty seems to be entirely removed by lining the suspension-box with a soft metal, which yields whenever any part takes an undue proportion of the weight.

"Contrivances bearing some resemblance to this had been previously attempted, but none of them were attended with sufficient success to warrant a general adoption. Some of Mr. Boyden's wheels, suspended in this manner, have now been running about six years, and it is believed that in every case, without any exception, where the work has been properly done in the first place, this mode of suspension has proved perfectly satisfactory.

"Very truly yours,

"JAMES B. FRANCIS."

"To Mr. John Weale."

The turbine has been in use in the United States about nine years. It is believed that the first were constructed under the direction of Mr. Ellwood Morris, an eminent Engineer, of Pennsylvania; they were subsequently more profoundly constructed after Fourneyron.

In the year 1844, Uriah A. Boyden, a very eminent Hydraulic Engineer, of Massachusetts, designed a turbine of about 75 horse-power for the Appleton Company at Lowell, Massachusetts, containing many new features, never before suggested: its success was remarkable for a first attempt on so difficult a subject. Soon after, Mr. Boyden designed and superintended the construction of three others of about 200 horse-power each, for the same Company. By the terms of the contract, their coefficient of effect was to be ascertained, the compensation being based upon their efficiency: the experiments were performed with an accuracy beyond all precedent, and the result was triumphant, the useful effect being considerably above 80 per cent. of the power expended.

The drawings represent a turbine constructed by the Lowell Machine-Shop Company, from my designs, intended to give 150 horse-power: it is 8 feet 4 inches in diameter, to operate under a fall of 13 feet.

Fig. 1 is a general plan of the entire apparatus.

„ 2 is an elevation of the same.

„ 3 is a section.

„ 4 is a plan, on a larger scale, of the floats and guide curves.

The following references apply to all the plans.

- a*, The masonry of the wheel-pit, faced with large blocks of granite, backed with rubble masonry laid in hydraulic cement.
- b*, The sheet-iron pipe conducting the water to the turbine.
- c*, The throttle-gate, to shut the water off from the turbine, either for examination or repairs: the apparatus for moving this gate is not represented.
- c'*, The leak-box for the purpose of collecting the leakage of the throttle-gate, and for carrying it off in a pipe when repairs are required on the wheel, &c.
- d*, The cast-iron framing supporting the upright and horizontal shafts of the wheel.
- e*, The suspension-box, which is made to fit the corresponding parts of the upright shaft by a lining of soft metal, principally tin, which is melted and poured into the outer shell, the necks being in place.
- e'*, The gimbal.
- f*, Levers for moving the speed-gate.
- g*, Rack for the same purpose.
- h*, Pinion-shaft for the purpose of moving the levers and rack.
- i*, Wooden staves of the diffuser.
- k*, Circular iron beams, to which the staves are fastened.
- l*, The governor.
- m*, The ratchet-wheel, fast on the worm-shaft.
- n*, The crank carrying the rocker.
- o*, Connecting rod.
- p*, The rocker carrying the palls.
- r*, The rod for moving the shield by the action of the governor.
- s*, The shield: when the governor is running at the speed intended, the shield protects the ratchet-wheel from the action of the palls: if the speed changes a small amount, only a few of the teeth of the ratchet-wheel are acted on at each vibration of the rocker; if there is a great variation of speed, a much greater number of the teeth of the ratchet-wheel are acted on at each vibration: the number of teeth exposed to be acted on is proportional to the variation of the governor-balls from their normal position.
- t*, The worm driving the pinion-shaft.
- u*, The worm-wheel fastened on to the pinion-shaft.
- v*, Brackets fastened to the speed-gate.
- w*, The wheel, carrying the floats of Russia sheet iron, about $\frac{1}{8}$ th of an inch thick, grooved, tenoned, and riveted into the upper and lower rings of the wheel.
- x*, The speed-gate.
- y*, The disc, carrying the guides or leading curves of Russia sheet iron, about $\frac{1}{10}$ th of an inch thick, tenoned and riveted into the disc.
- z*, The disc-pipe, supported by the adjusting screws at the top of the curb.
- A, The main shaft of the turbine.
- B, The step for steadying the bottom of the shaft, lined with case-hardened wrought iron; the pin in the bottom of the shaft is of cast steel.
- C, The timber floor of the wheel-pit, covered with 3-inch planks.
- D, Cast-iron beams, to distribute the weight on the columns over the timber floor.
- E, Columns supporting the diffuser beams *k* and the beams F.
- F, Beams supporting the curb or acting as braces from the sides of the wheel-pit.

G, The lower curb, of cast iron; the outer surface is turned cylindrical, for the purpose of receiving properly the packing of the speed-gate.

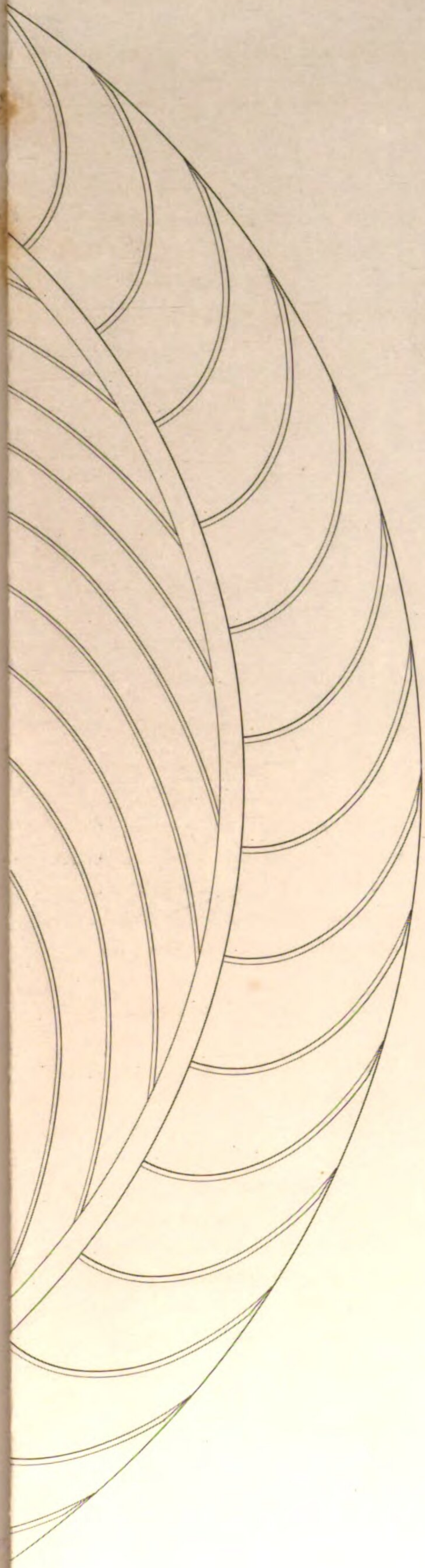
H, The upper curb, also of cast iron, about $1\frac{1}{4}$ inch thick.

I, Weights counterbalancing the weight of the speed-gate.

This is the fifth wheel constructed in Lowell having the same diameter and form of floats and guides; the other parts of the apparatus being adapted to local circumstances.

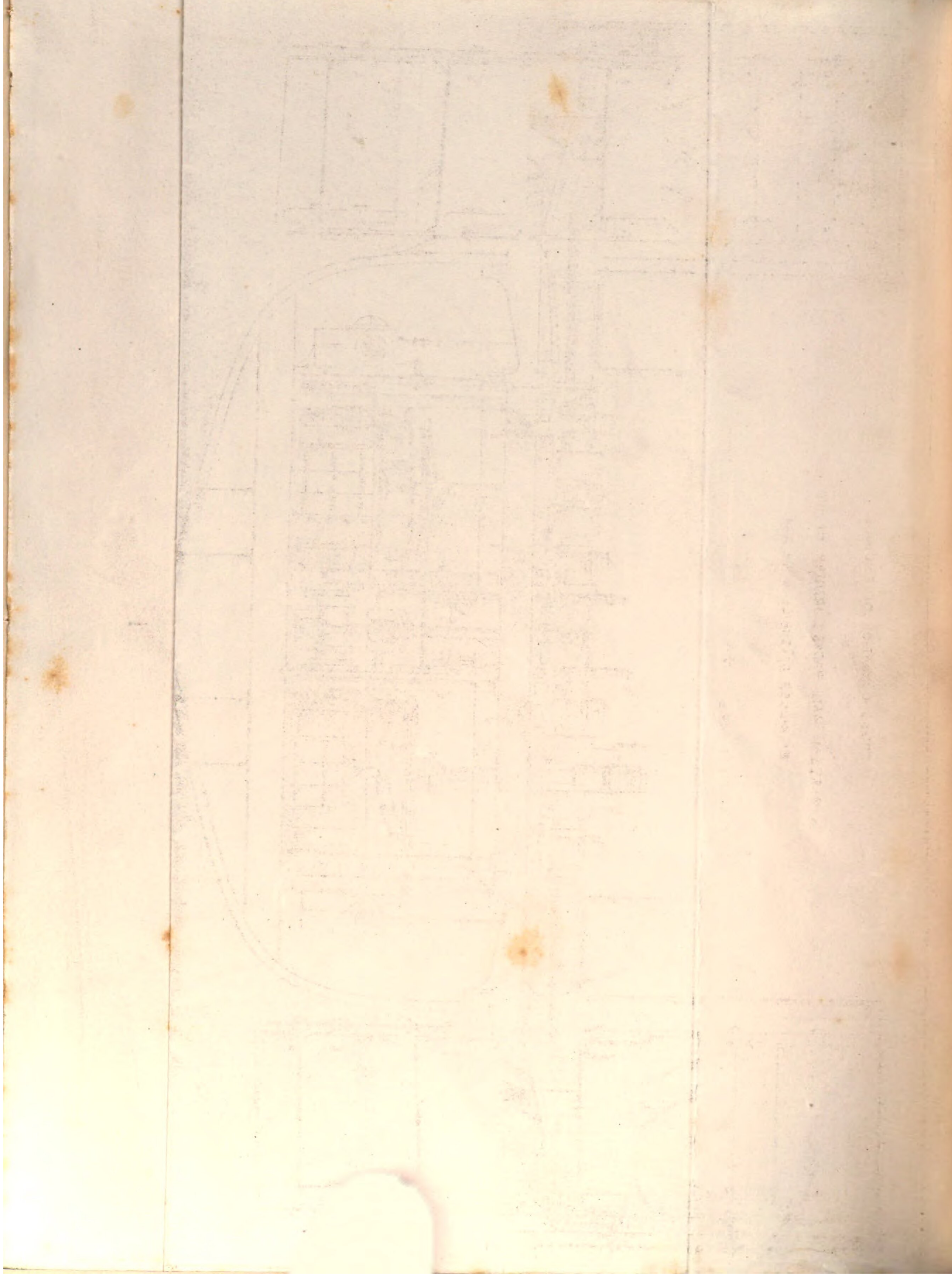
There are now thirty turbines in Lowell, varying in diameter from $2\frac{1}{4}$ feet to 10 feet 1 inch; there are also many powerful turbines in other parts of New England; and the larger proportion of those which have been constructed on scientific principles were designed by Mr. Boyden.

J. B. F.

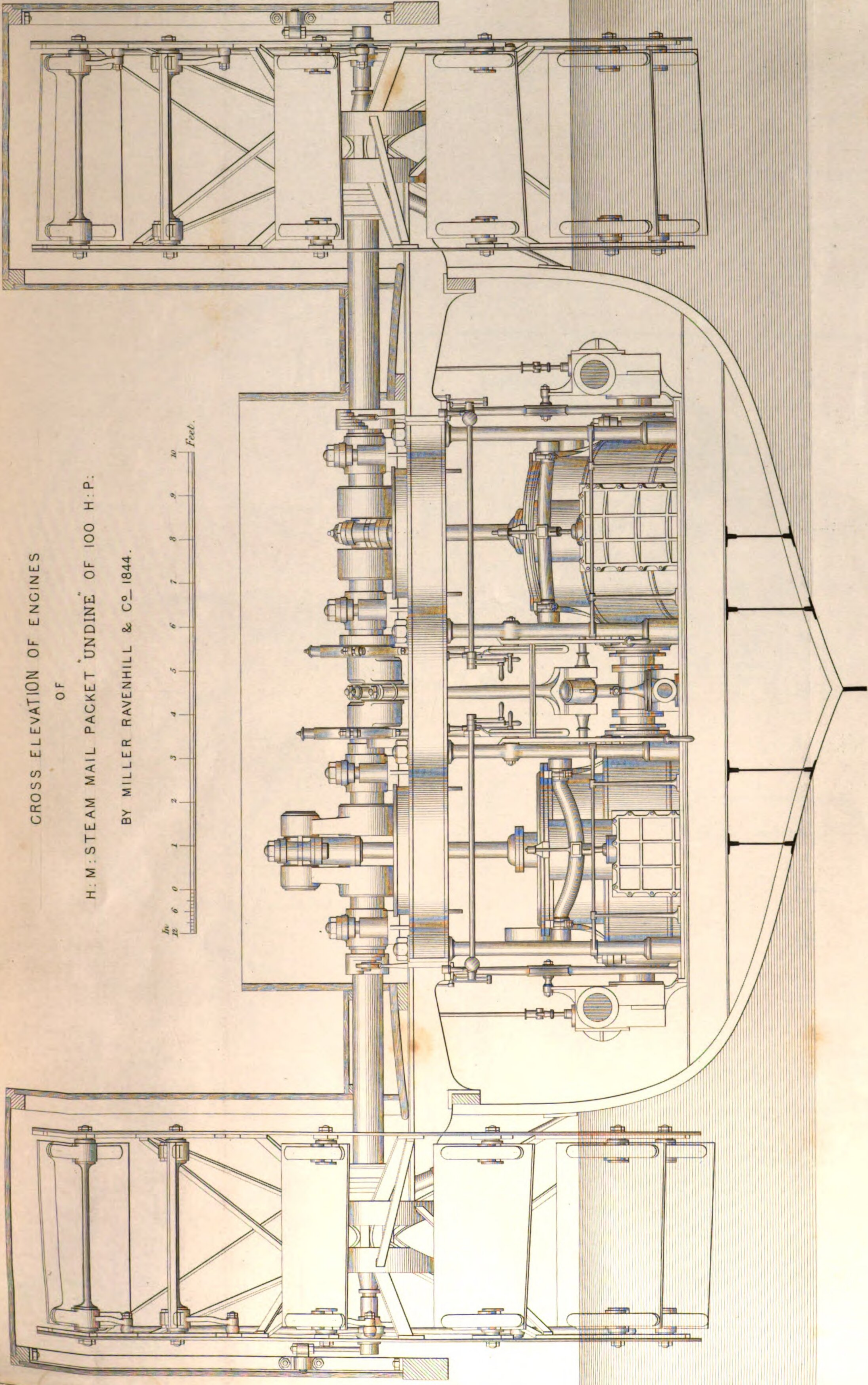
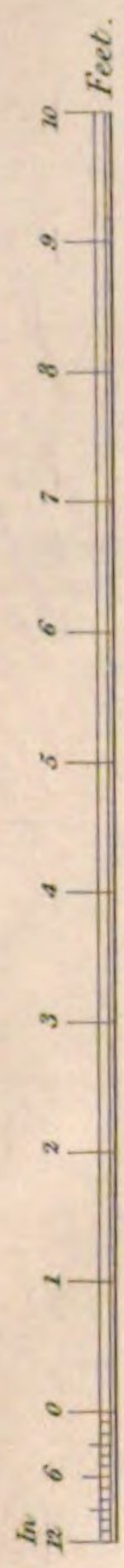


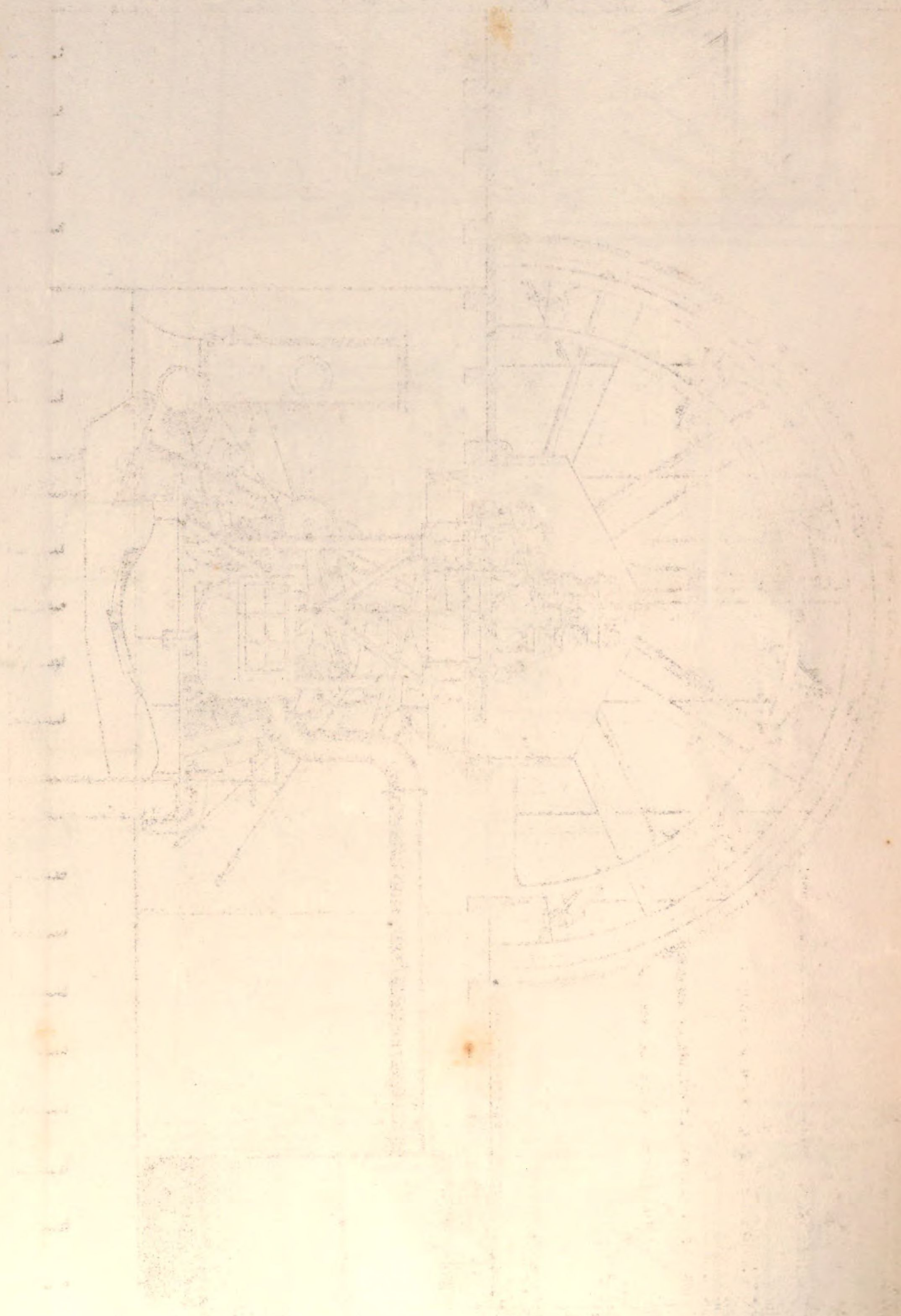
London, John Weale, 1851.

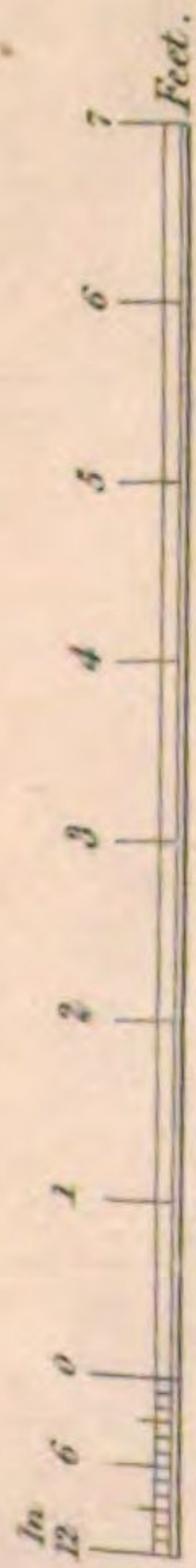
W.A. Beaver, Sc.



CROSS ELEVATION OF ENGINES
 OF
 H:M: STEAM MAIL PACKET "UNDINE" OF 100 H.P.:
 BY MILLER RAVENHILL & CO. 1844.





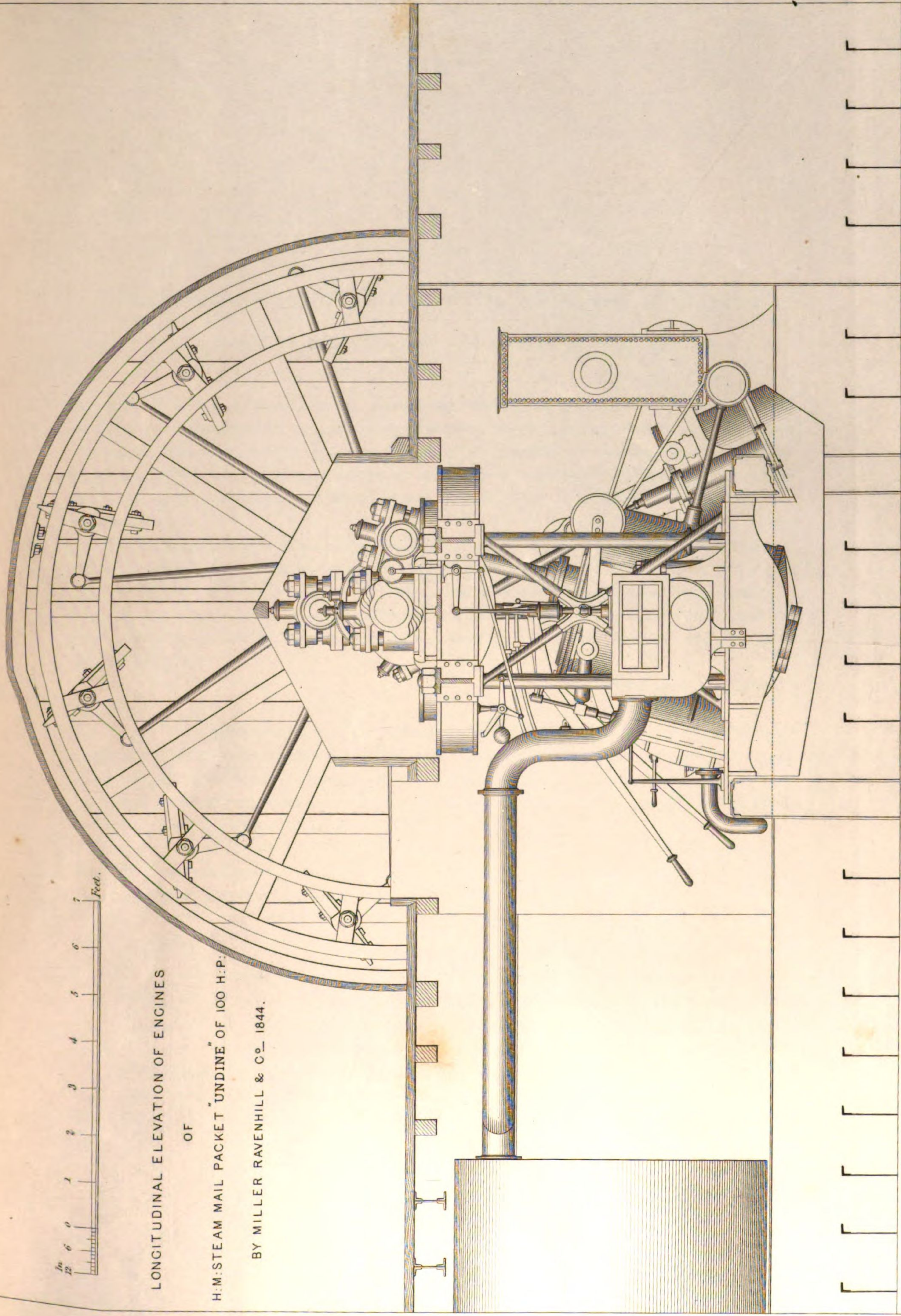


LONGITUDINAL ELEVATION OF ENGINES

OF

H.M. STEAM MAIL PACKET "UNDINE" OF 100 H.P.

BY MILLER RAVENHILL & CO. 1844.



ON THE

INTRODUCTION AND PROGRESSIVE INCREASE OF SCREW

PROPULSION IN HER MAJESTY'S NAVY.

ALTHOUGH various propositions for many years were made from time to time to use the screw as an instrument of propulsion, and a great variety of experiments tried in boats and small vessels, yet neither the reasoning of the projectors nor the results of their experiments appear to have carried conviction to the minds of most men that this kind of propeller could be usefully employed, or at all events that it could successfully compete with the paddle-wheel.

The immediate cause of its introduction into the Navy was the successful performance round Great Britain and elsewhere of the 'Archimedes,' a vessel of 237 tons, built in the year 1838 by the Screw Propeller Company, with a view of ascertaining the value of the invention. She was first tried against a paddle-wheel vessel in 1840, and the results of the trials are contained in the following Report, the first official one made to the Board on the subject of Screw Propulsion.

Dover, May 2nd, 1840.

SIR,

IN pursuance of the instructions of the Lords Commissioners of the Admiralty, as conveyed to us in your letter dated 25th ultimo, directing us to examine and report upon the principle on which the 'Archimedes' steam vessel is propelled, we beg to state that we have made such experiments as were practicable, and we request that you will be pleased to submit to their Lordships the following Report.

On our arrival at this place we made arrangements with Commander Boteler, by which the 'Widgeon' mail steam packet was placed at our disposal. The following statement shows the comparative size, power, and immersion of the two vessels.

Names.	Tonnage.	Diameter of Cylinders.	Length of Stroke.	Mean draught of Water.
Widgeon. . . .	162	39 inches	3 feet 1 inch	7 feet 3 inches
Archimedes . . .	237	37 inches	3 feet	9 feet 4 inches

The 'Widgeon' is the fastest packet upon the Dover Station. She has 10 horses' power more, and 75 tons' burthen less, than the 'Archimedes;' and the mean draught of water of the former is 2 feet 1 inch less than that of the latter.

EXPERIMENTS.

1. Our first trial was upon a run of 19 miles upon a w. s. w. course from Dover Roads, with a light breeze aft and smooth water, but without sails. The engine of the 'Archimedes' worked 27 strokes a minute, and the speed of the vessel was $8\frac{1}{2}$ knots per hour. The 'Widgeon' performed the whole distance in six minutes less than the 'Archimedes.'

2. In returning the above 19 miles to Dover Roads, against a moderate head wind, without sails, the engine of the 'Archimedes' worked 26 strokes per minute, and her speed was from $7\frac{1}{2}$ to 8 knots per hour. The 'Widgeon' performed the distance in 10 minutes less than the 'Archimedes.'

3. The third experiment was a run of 19 miles, from Dover Roads to Calais Roads, in a perfect calm, with the sea smooth as glass. 'Archimedes' engine worked 27 strokes per minute, and her speed was from $8\frac{1}{2}$ to 9 knots per hour. The 'Widgeon' performed the distance in $3\frac{1}{2}$ minutes less than the 'Archimedes,' and the whole time occupied by the latter on this trial was 2 hours $9\frac{1}{2}$ minutes.

4. In returning the above 19 miles back to Dover Roads the weather was dead calm, and the sea smooth as before. The French mail packet, called 'La Poste,' started at the same moment. Speed of the 'Archimedes' and her engine as before. 'Widgeon' ran the distance in 4 minutes less than 'Archimedes,' and the 'Archimedes' in 25 minutes less than 'La Poste.' The latter has engines of only 50 horses' aggregate power.

5. On this trial there was a fresh breeze at east, and moderate sea. Both vessels set the whole of their sails, the 'Archimedes' carrying much more canvas than the 'Widgeon.' The run was as before, from Dover to Calais, 19 miles, close hauled. 'Archimedes' engine from 27 to 28, and her speed from 9 to $9\frac{1}{2}$ knots. 'Archimedes' ran the distance in 9 minutes less than the 'Widgeon.'

6. In returning to Dover, with a fresh breeze abeam and all sail set, 'Archimedes' engine 28, and speed 10 knots, she performed the distance in $5\frac{1}{2}$ minutes less than the 'Widgeon.'

REMARKS.

These trials clearly prove that the speed of the 'Archimedes' is slightly inferior to that of the 'Widgeon' in light airs or calms, and in smooth water; but as the steam-power of the former is 10 horses less, and her burthen 75 tons more than the 'Widgeon,' it is evident that in these vessels the propelling power of the screw is equal, if not superior, to that of the ordinary paddle-wheel. In this respect, therefore, Mr. Smith's invention may be considered completely successful.

It is also plain, from the second trial, that in the steaming against even a light air of wind, the low masts and snug rig of the 'Widgeon' gave her an advantage over the 'Archimedes,' with loftier masts and heavier rig; and although the prevalence of calms prevented our trying them farther upon this point in blowing weather, we are satisfied that in strong breezes the advantage of the 'Widgeon's' low rig in going head to wind would be still more apparent.

On the last two trials, however, the power of the sails operated strongly in favour of the 'Archimedes,' as she then beat the 'Widgeon,' and made the passages between Dover and Calais in less time than it has ever been performed by any of Her Majesty's mail packets.

The 'Archimedes' went upon this occasion from Dover to Calais in 2 hours 1 minute, and returned in 1 hour 53½ minutes.

There are two points of great practical importance respecting the screw propeller which ought not to pass unnoticed. First, the noise made by the spur-wheels used in giving the necessary velocity to the propeller shaft. Secondly, the liability of those wheels to rapid wear and to accidental derangement. The noise alone, we conceive, would prevent its being applied to any of Her Majesty's packets in particular. Mr. Smith, however, proposes to obviate this objection by substituting spiral gearing in lieu of the present cogs; and a model of this method will be submitted to their Lordships with this Report. As it is the intention of Mr. Smith shortly to make trial of this alteration, we abstain from giving any opinion upon its merits at present.

It is, however, in propelling vessels of war that the value of Mr. Smith's invention will probably be experienced. In such cases, the rumbling noise in the ship made by the spur-wheels is of no great moment, even if it cannot be overcome; for outside the vessel, this noise is not audible to so great a distance as that made by the common paddle-wheel. A ship fitted with the screw propeller may be used either as a sailing or a steaming vessel, or as both, if required; for we ascertained by experiment that the engine can be connected or disconnected with ease, and in any weather, in two or three minutes. In carrying a press of sail, the inclination of the ship does not diminish the propelling power of the screw, nor lessen the ship's way, as with the ordinary paddle-wheel. The getting rid of paddle-boxes also leaves the broadside battery altogether clear of obstruction, and in boarding an enemy's vessel would allow of the ships lying close alongside of each other.

In conclusion, it is proper to state, that the operation of the screw facilitates the steering, and accomplishes the backing of the ship as easily as the common paddle-wheel.

We have the honour to be, Sir,

Your most obedient servants,

(Signed) E. CHAPPELL, Captain. T. LLOYD.

The Secretary of the Admiralty.

It is obvious that in the 'Widgeon' and 'Archimedes,' which differed materially both in size and form, an exact comparison could not be made between the performance of the screw and that of the paddle; but the result of the trials clearly showed, especially when the peculiar fitness of the screw for war purposes was taken into consideration, the propriety of trying this new instrument in a less equivocal manner.

With this view the 'Rattler' was ordered to be built, and, that the experiment might be conclusive, so far as a trial between two vessels could make it so, she was constructed on the same lines as the 'Alecto,' the after-part being lengthened for the insertion of the screw, and fitted with engines of the same power and on a plan which had been previously tried in paddle-wheel vessels.

The River trials of the 'Rattler' lasted from October, 1843, to the beginning of 1845, and from them it was clearly seen that the screw might be advantageously reduced from two half-turns to about one-third of this length, an alteration which greatly reduced the weight, facilitated the operation of shipping and unshipping, and appeared to render unnecessary the

wounding to so great an extent the after-part of the vessel. Before this last point was decided, it not being evident that the good performance of the shorter screw was not attributable to the greater clearance which the reduction of its length had caused, the screw aperture was partly filled up in a temporary manner, so as to leave the shorter screw the same clearance as the longer one originally had. The result of this experiment showed that the screw aperture in future vessels might be constructed of very moderate dimensions without lessening the effect of the propeller.

It was also evident from these trials that the screw, as an instrument of propulsion in smooth water, was not inferior to the paddle-wheel.

In the early part of the year 1845 the 'Rattler' proceeded, in company with the 'Victoria' and 'Albert,' and the 'Black Eagle,' from Portsmouth to Pembroke. When rounding the Land's End, and steaming against a strong head wind, both these vessels, as might be expected, showed a great superiority, their power being much greater than the 'Rattler's' in proportion to their resistance, and their paddle-floats being constructed on the vibrating principle. This comparative failure of the 'Rattler' made an unfavourable impression on the public mind as to the efficiency of the screw against wind and sea in heavy weather, and this impression in some degree still remains, although no conclusive proof of its inferiority in this respect has yet been afforded; for in the subsequent trials of the 'Rattler' with the 'Alecto' at sea, against strong head winds, the only occasion on which the screw has been fairly tried under such circumstances against the paddle-wheel, no decided advantage on either side seems to have obtained, the advocates of the screw and those of the paddle respectively claiming the superiority, while in fine weather the screw is admitted to have had some advantage over the paddle.

The 'Rattler' was next tried against the 'Vesuvius' in a run from the Thames to Leith, and showed in respect of speed a decided superiority over the paddle-wheel vessel, whose power, as compared with her tonnage, was greater than that of her competitor.

Before joining the squadron under the command of Rear-Admiral Hyde Parker, in July, 1845, the 'Rattler' was employed to tow the 'Erebus' and 'Terror' to the Orkney Islands, and she appears to have performed this service to the satisfaction of Sir John Franklin.

Before this time, however, the 'Bee' was constructed with both screw and paddle-wheel for the instruction of the Officers of the Royal Naval College, the 'Dwarf' purchased, the conditional speed of 12 miles per hour having been realized, and the 'Fairy' built for the use of Her Majesty; but although the results of the experiments made upon the two latter vessels threw some light upon the action of the screw, and satisfactorily showed that by its means a comparatively high rate of speed could be obtained, yet they could scarcely be regarded as proper data on which to proceed in the construction and fitting of larger vessels.

Some private companies also were led to entertain so favourable an opinion of the screw that they ventured to try it; two of them on a large scale. The 'Great Britain,' of 3000 tons, arrived in the Thames in January, 1845, and the 'Great Northern,' of 1515 tons, two years previously. Neither of these vessels was successfully worked for any length of time, the former having been wrecked and the other broken up, but the results obtained, as regards the application of the screw, were considered satisfactory.

These results, probably, together with those obtained from the preliminary trials of the 'Rattler,' and, above all, the favourable reports by Naval Officers of her performance at sea, induced the Board, in 1845, when the Steam Navy was about to be considerably increased, to determine that the screw should be adopted. They determined at the same time that the engines should be so constructed that every part of the machinery would be below the water-line, an important deviation from the practice which had previously existed, and one which must be regarded as a great step towards rendering steam vessels fit for all the purposes of war. The Board likewise ordered the screw and its fitting to be so arranged, that the operation of shipping and unshipping might easily be performed in any weather, thus rendering the vessels, as far as practicable, perfect sailing ships whenever steam-power was not required.

It thus became necessary, in order to fulfil the various requirements, to devise new forms of engines and new modes of application, there being at that time no kind of engine which would effectually answer the purpose. All the eminent marine engineers in the country were therefore called on to propose that construction and arrangement of engine which they might severally think the best adapted, the dimensions of the propeller, and the number of revolutions it would be required to make, being furnished for their guidance, and the necessity of keeping the whole of the machinery below the water-line being insisted on. Beyond these necessary conditions the manufacturers were left unfettered, and they, as might be expected, seeing a new and wide field open for their exertions, submitted a great variety of designs, the result of their great experience and mechanical ability.

These designs differed widely from one another; some were with and some without gearing, and many of them appeared to possess great merit. Of these selections were made, giving to nearly all the most eminent engineers an opportunity of carrying into effect one at least of the plans which they severally proposed, and in no instance giving orders for more than two engines of the same description, a decision which seems to have been judicious, when it is borne in mind that little experience had then been acquired in this novel application of steam-power.

In the year 1845 tenders were accepted for fifteen pairs of screw engines for vessels of various dimensions, and, on the suggestion of the Harbour Defence Commission, eight pairs for what were originally termed Block Ships, four of them being line-of-battle ships and four frigates. The good performance of the former class seems to have altered their original destination from mere floating batteries to sea-going ships, calculated to serve with advantage in conjunction with a fleet. Of the frigate block ships, one only out of the four has been ordered to be fitted, and with smaller engines than those originally intended for her. She is not yet completed.

In order still further to test the comparative value of the screw, one paddle-wheel vessel, the 'Basilisk,' was ordered to be built on the same lines as the 'Niger,' and to be fitted with engines of the same power. The result of the trials recently made between these two vessels may be shortly stated. In fine weather, when equal engine-power was exerted, there was little difference of speed, and when sail could be used the advantage was in favour of the screw. There was no opportunity of trying the vessel's head to wind in heavy weather, an important point which hitherto remains undecided by actual experiment.

The expenditure of coal was much greater in the 'Niger' than in the 'Basilisk,' but this disadvantage arose from the construction of the boilers and engines, and not from the difference between the propelling instruments.

As far as trials have been made of the various kinds of screw engines, success to a greater or less degree may be said to have been the result of all; certainly none of them can be regarded as failures; but the pecuniary loss sustained by most of the manufacturers, and the great anxiety felt by all, can be fully appreciated by themselves alone.

Sufficient experience has not even yet been acquired for the basis of a sound opinion as to the particular form of engine which should be adopted, but the selection may now be confined within comparatively narrow limits, and experience already points out the strong probability that gearing may be altogether dispensed with, thus entirely obviating the noise so much objected to in the first screw vessel, increasing the simplicity of the machinery, and reducing its bulk and weight.

One important fact, however, which during the early trials of the screw most persons doubted, has been incontestably proved, and has already led and is calculated to lead still further to a very extensive application of the screw as an auxiliary. It has been established beyond all question that it is unnecessary to adopt complex contrivances for altering the angle of the screw, or to use, as was done in some private vessels, differential gearing, to enable the engines to work advantageously under the varying velocity of the vessel, occasioned by using the sails to a greater or less extent in conjunction with steam-power. If, for example, an engine and screw be arranged to drive a vessel at the rate of five knots, the number of strokes given out by the engine will not be inconveniently increased, or the effect of the screw diminished, when by the addition of sail-power the rate of the vessel is increased to 10 knots, the simple screw thus becoming a convenient and efficient auxiliary in all classes of ships, and producing, whenever used in conjunction with sail-power, a higher rate of speed than could be obtained under the same circumstances by sail alone. This view is confirmed by the successful performance of many private vessels fitted with auxiliary power. The small vessels first built traded to ports at no great distance, but their voyages have already been extended to Constantinople; and it now seems highly probable, judging by what has been accomplished, that fine sailing vessels fitted with auxiliary screw-power will be found able, if not to rival, at least to approach, full-powered and expensive steam ships, in respect of their capability of making a long voyage with certainty, and in a reasonably short time.

Another application of the screw, although inferior in importance to its application as a propeller to ordinary ships, is certainly deserving more attention than has hitherto been paid to it, namely, as a manœuvrer to those large ships in which engines of considerable power cannot be placed, or in which it is considered unadvisable to do so. No doubt can be entertained of the efficiency of such an instrument worked by an engine of even 50 horses' power. The full extent, however, of its utility cannot, perhaps, be thoroughly appreciated until it shall have been extensively tried in Her Majesty's Navy.

The proper form of the run of screw vessels being at the time of their introduction, and for some time after, a matter rather of speculation than a deduction from known principles or facts, a wide difference of opinion on this important point obtained among those who were engaged in designing these vessels; and the Board, in order to ascertain within certain limits

the form which ought to be adopted, directed some experiments to be made on the 'Dwarf.'

These experiments were carried out by attaching in a temporary manner to the iron plate some pieces of wood, so as to render her after-body as full as that of any of the vessels then in progress. The great reduction of speed from 9 knots to less than 4 knots, caused by this alteration, unequivocally showed the impropriety of adopting such a form; and all the vessels then in course of construction, except those not sufficiently advanced to render necessary any alteration, were to a greater or less extent improved in the form of their stern immediately before the screw aperture.

The great importance, or rather the necessity, of introducing forms calculated to aid the action of the screw, cannot be questioned in those cases in which a high speed is regarded as indispensable, it being evident that in such cases a proper form is also indispensable, for without it the object of high speed is not attainable; but even when a moderate speed only is required, a suitable form, although not, as in the former case, absolutely necessary for obtaining the required speed, will be seen to be of greater importance than is perhaps commonly supposed, by a consideration of the great waste of power and its attendant evils occasioned by the adoption of the contrary form. If, for example, a ship, which, if of the proper form, would be propelled at $7\frac{1}{2}$ knots, is propelled at 6 knots only, about one-half of the engine-power is thrown away, thus wasting half the original cost of the engines and boilers, incurring double the current expense of wear and tear, consuming double the quantity of fuel, and losing the advantage of dispensing with half the weight of engines, boilers, and coals, and reducing by one-half the space which they occupy in the ship; or if the weight and space were not calculated to produce serious inconvenience, throwing away the capability of carrying fuel for perhaps three times the number of days. Probably such considerations as these induced the Board to order the after-bodies of so many screw vessels to be improved, with a view of insuring advantages which were neither doubtful nor of small moment, and which appeared to outweigh the expense of making the necessary alterations. Subsequent experience clearly proved the soundness of the views thus carried out.

The following Table contains some particulars of all the screw engines which have been ordered, as well as an account of the alterations which from time to time have been made in their application, and of the results thereby produced.

It will be seen that the screw engines ordered from—

1841 to 1844 amount to	. . .	8
in 1845	„ . .	26 including 'Erebus' and 'Terror'
in 1847	„ . .	9
in 1848	„ . .	2 for pinnaces of 'Investigator' and 'Research.'
Total number	. . .	45

The numbers in the last column of the Table, and in the column next but one preceding it, show approximately the relative excellence in respect of speed, of the forms of the various ships, conjointly with the relative efficiency of the propeller, as adapted to each of them.

The formulæ by which the calculations are made are founded on the assumption that the resistance of a ship varies as the square of her velocity, and therefore that the power required

to produce that velocity varies as the cube, and that the useful effect of the engine, that is, the effect which remains after deducting the power absorbed in overcoming friction, working air-pumps, &c., bears a constant ratio to the power developed in the cylinder, known by the term 'Indicated Horse-Power.' The resistance is, in the first of these columns, assumed to vary, *cæteris paribus*, as the area of the midship section, and in the last column as the cube root of the square of the displacement.

None of these assumptions, however, more especially the last two, are absolutely correct, but probably they are not so far from the truth as to render useless and uninteresting a comparison, of which they are the basis, made between the performances of any two screw ships; while between two vessels which do not materially differ in engines and displacement, or in the area of their midship sections, such a comparison is not only highly interesting, but it may prove of great value in pointing out the forms of ships and proportion of propellers which ought to be adopted. In some striking cases it is scarcely necessary to make any other comparison than that of speed. For example, the 'Teazer,' after her form had been improved, went above a knot an hour faster with 40-horse engines than she had previously gone with engines of 100 horse-power. Again, these engines of 100 horse, when transferred to the 'Rifleman,' a vessel approaching to double the tonnage, drove her, after her form had been altered, as fast as she was previously driven by engines of double the power, and nearly 2 knots faster than the same engines drove the smaller vessel before the alteration of her after-body.

Somerset House, May, 1850.

[See Table.]

R A T			
	Vessel's length to breadth.	Screw's pitch to diam.	Midship section to Screw's disc.
Aja	3.625	1.25	3.73
I4	"	1.12	4.01
An8	4.1	1.4	3.09
Ar	5.32		
I3	"	0.86	5.84
Ar2	4.37	0.96	3.07
Be5	5.17	1.21	3.76
Blc	3.73	1.25	3.67
Bri	5.53		
Co6	5.6	1.22	2.81
Cri			
Da7	5.28	1.22	3.09
I9	5.48	"	"
De	5.6	1.08	
Dw6	7.87	1.41	1.74
Ed			
En5	5.73	1.25	2.81
I9	"	"	3.01
En			
P			
Er	3.64		
Eu	5.32		
Eu			
Fab	6.84	1.5	3.2
I	"	1.29	2.74
For			
Gr	5.69		
Hi	5.28		
Hc6	3.8	1.25	4.08
Hc	3.83		
I	"		
Hc			
In			
I			
M	5.47		
I	"		
M	5.93	1.11	5.15
I	"	0.73	4.17
I	"	0.73	4.17
M	5.76		
Ni	5.6	1.36	3.28
I	"	"	3.19
I	"	"	3.47
Pl	5.48	1.05	3.06
I	"	0.92	2.99
I	"	0.81	2.97
Pl	5.09	0.77	3.45
I	"	0.62	3.2
I	"	"	3.78
I	"	0.52	3.48
R2	5.39	1.1	3.49
I	"	"	4.2
R9	5.3	0.91	3.06
I	"	0.81	3.55
R2	5.64	1.12	3.44
I	"	1.12	3.44
I	"	1.12	3.48
I	"	1	3.12
S	3.84		
I			
S	5.63	1.12	3.81
I	"	1	3.08
6			
I	5.96	1.29	5.21
I	"	1.4	4.22
I	5.19	1.16	2.74
I	"	"	3.09
I	"	"	3.08
I	"	"	3.09
I	"	1.11	3.11
I			
5	5.31		
I	"	1.18	3.02
I	5.32		
I	"		

he area of the midship section



J.H. Le Kaux Jr.

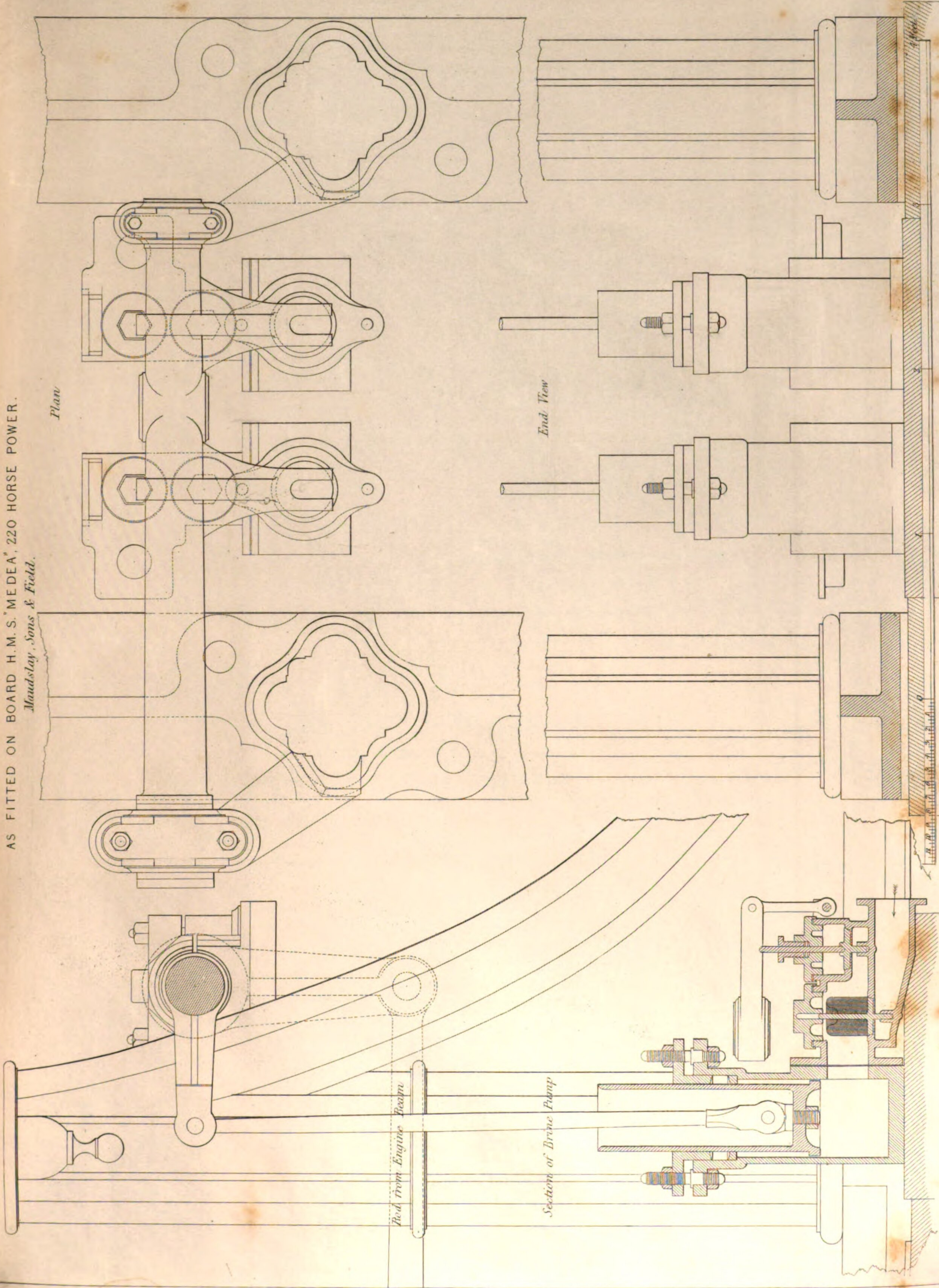
Published by John Weale, 59 High Holborn, 1852.

John Trickett del.

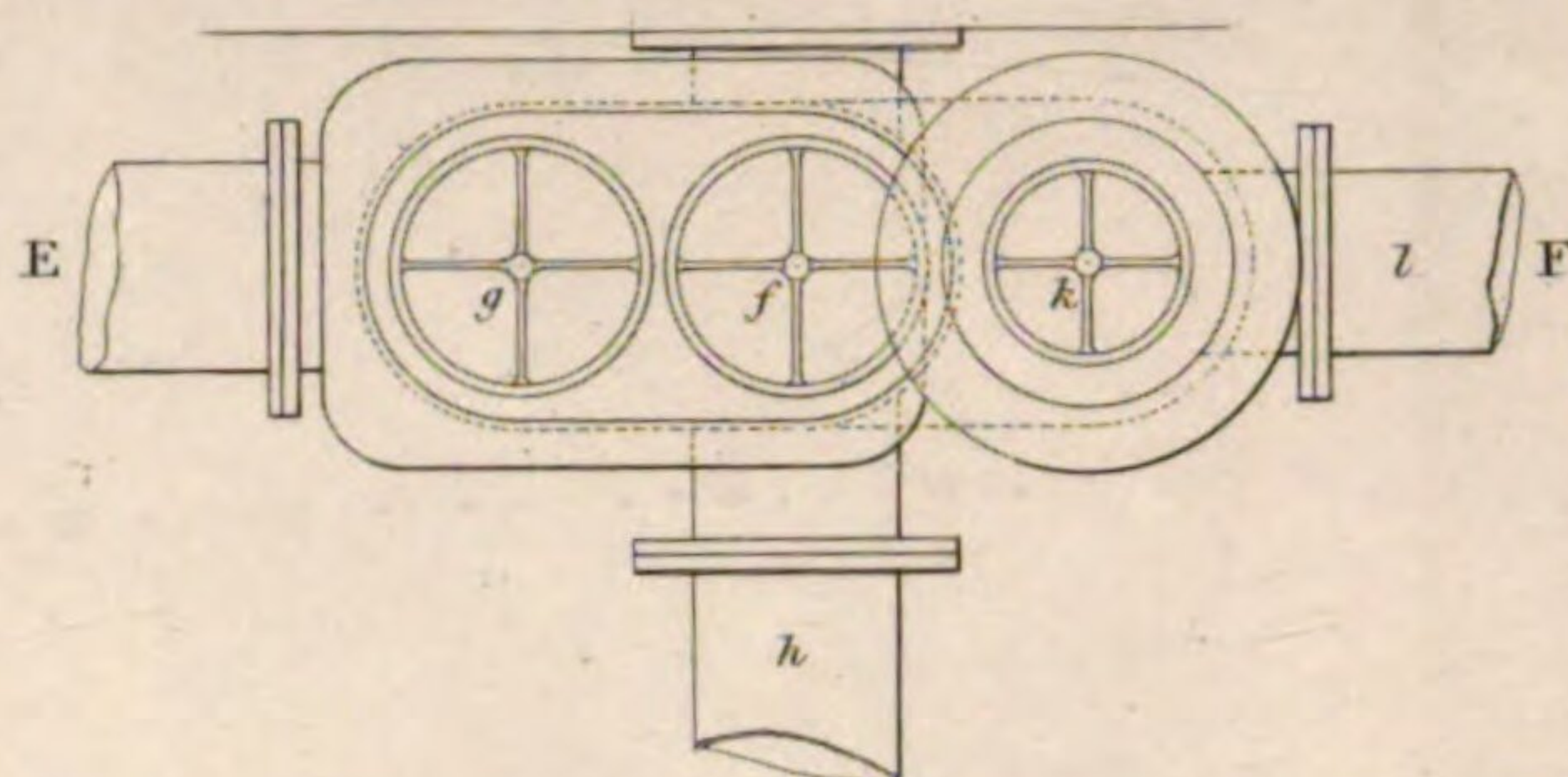
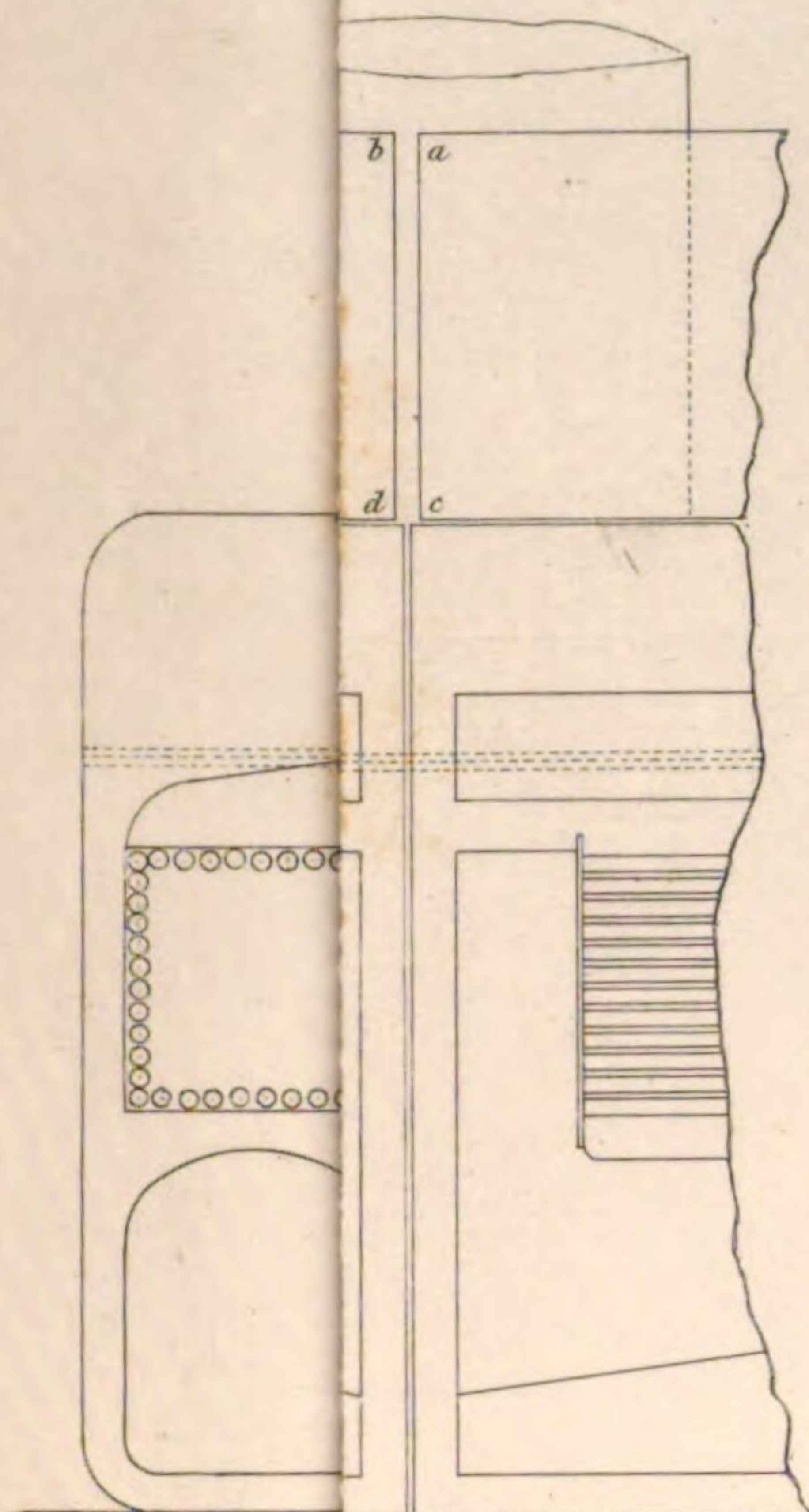
BRINE PUMPS.

AS FITTED ON BOARD H.M.S. "MEDEA", 220 HORSE POWER.

Maudslay, Sons & Field.

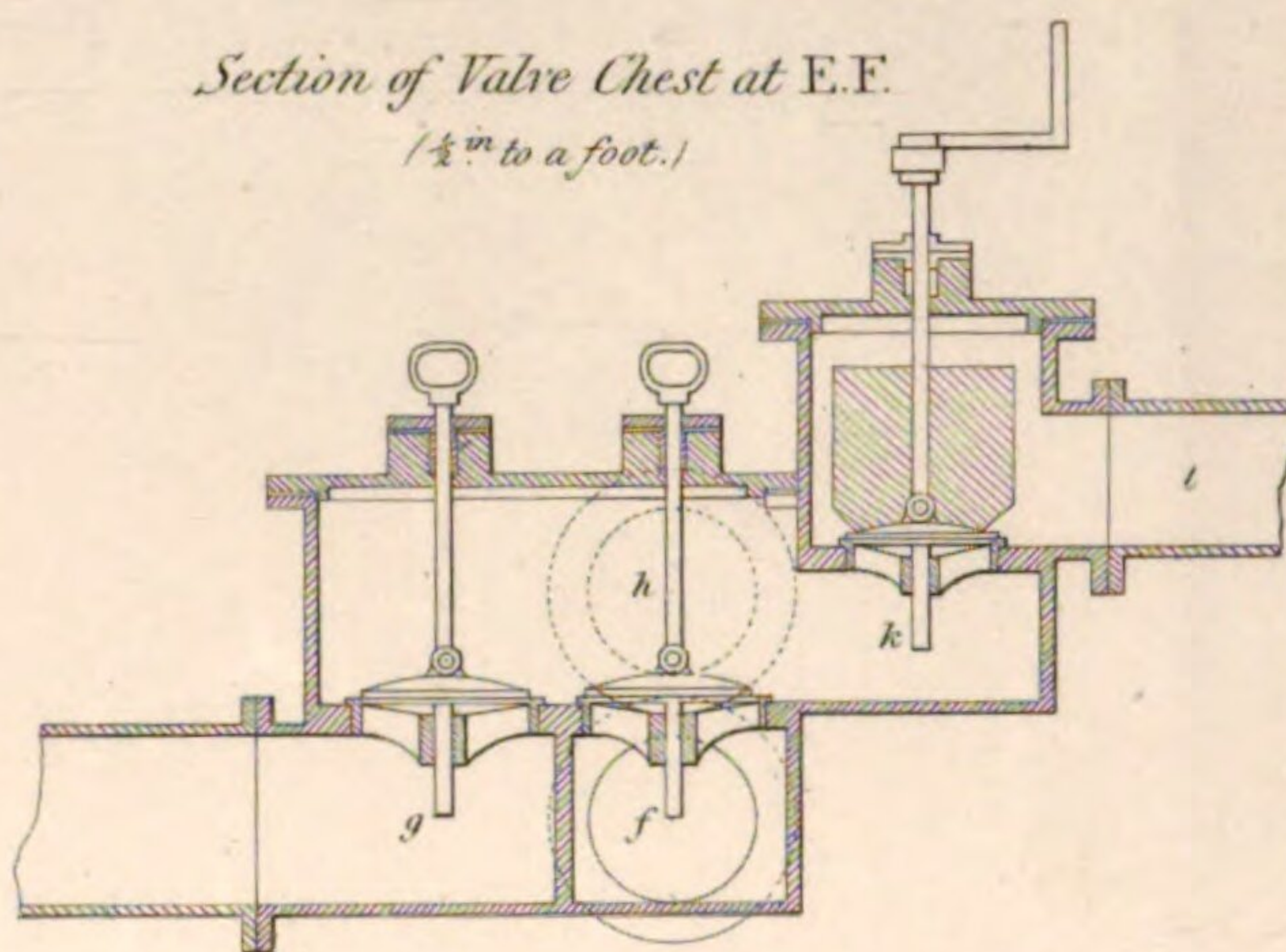


Plan.



Section of Valve Chest at E.F.

($\frac{1}{2}$ in to a foot.)



OF THE FOUR BOILERS WITH THE SUPPLEMENTARY STEAM CHESTS AND SHUT OFF VALVES.

on Board the "AVENGER" Steam Frigate.

Scale $\frac{1}{4}$ inch to a foot.

A

Supplementary Steam Chests one to each Boiler.
Shut Off Valves communicating between the
and Supplementary Steam Chests.
Shut Off Valves from the Boiler to the Main Steam Pipe.
Shut Off Valves from Supplementary Steam Chests to
Main Steam Pipe.
Safety Valve with the Waste Steam Pipe L.

1870



THE UNIVERSITY OF CHICAGO

LIBRARY

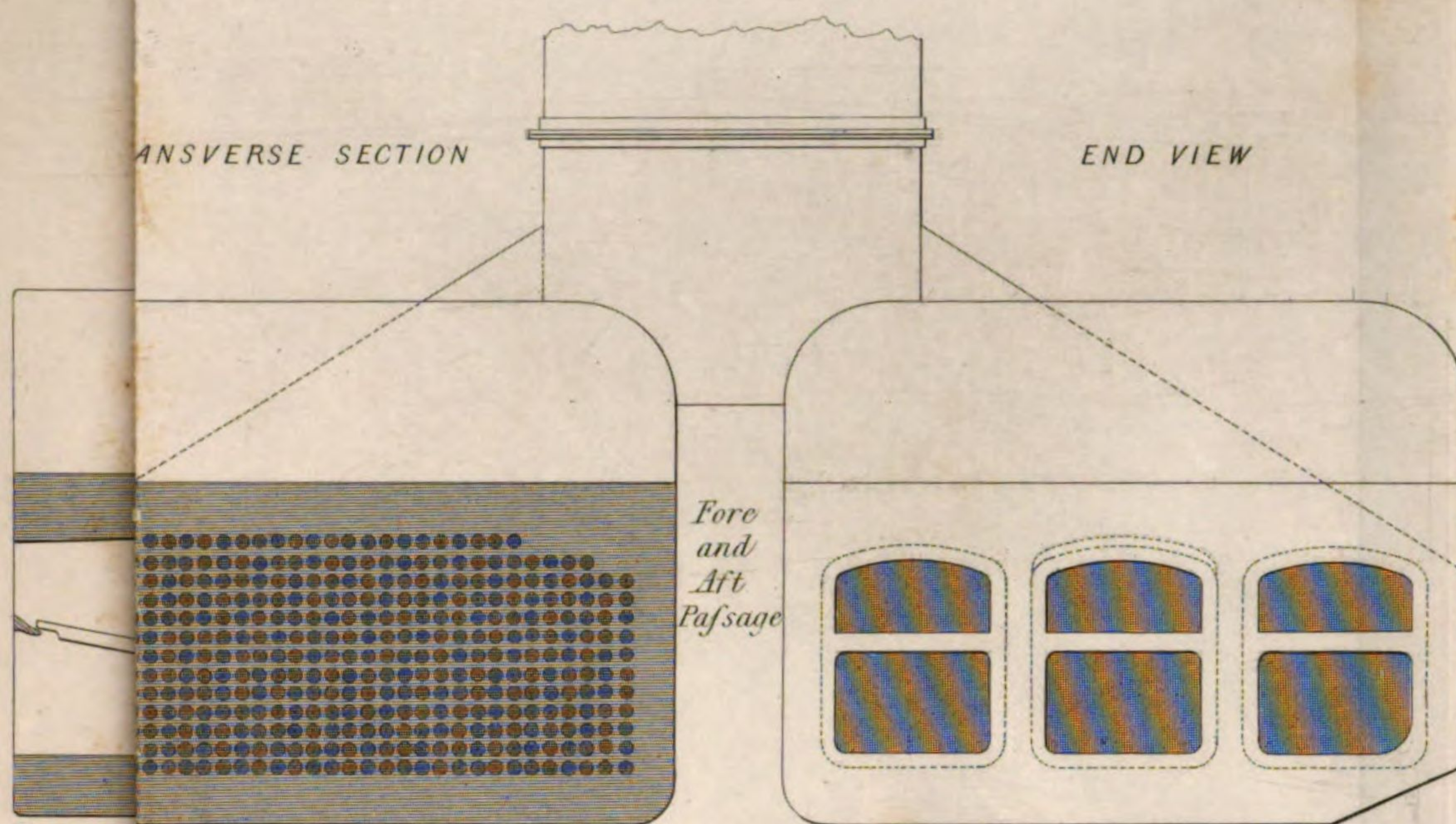
1870

CHICAGO

1870

CHICAGO

1870



BOILERS OF H.M. STEAM SHIP "NIGER".
OF THE COLLECTIVE POWER OF 400 HORSES.

fitted by

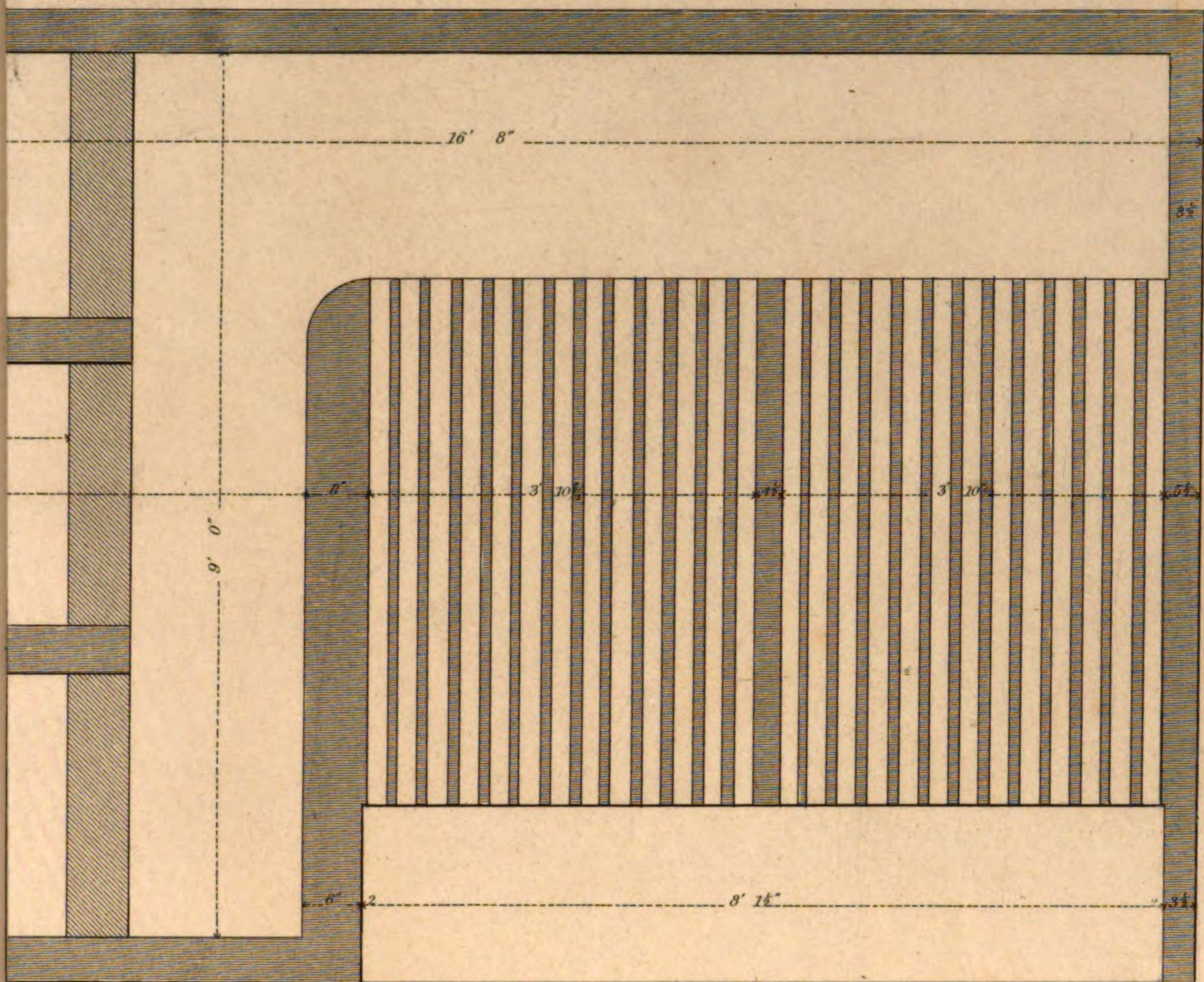
*MAUDSLEY, SONS & FIELD,
Engineers, London.*

Scale $\frac{1}{4}$ Inch to the foot.

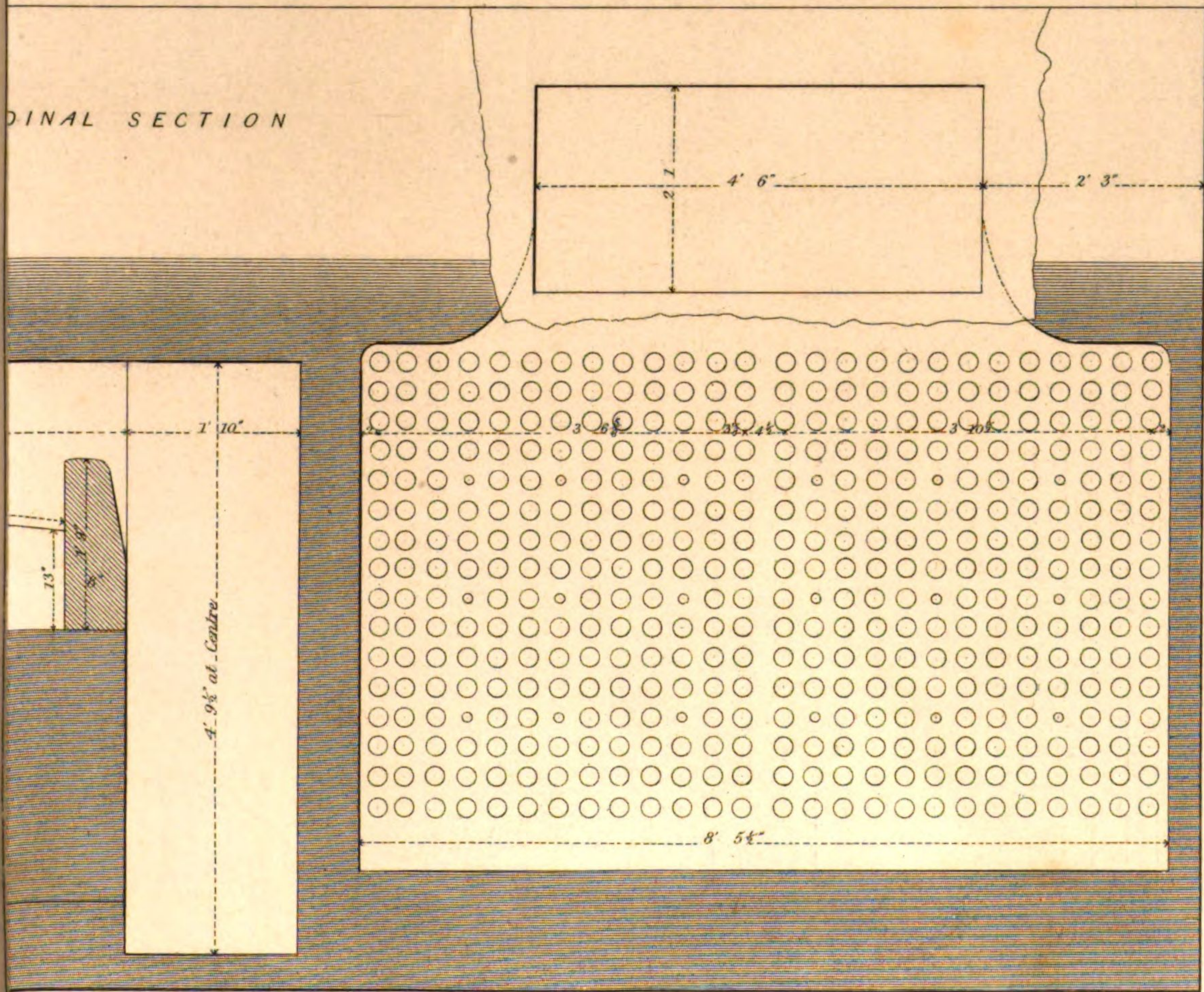
Stoke Holes forward and abaft

Reference A. Reflector, to reverberate the flame.

HORIZONTAL SECTION



DINAL SECTION



EXPERIMENTAL MILLING

WOOLWICH YARD

1861

Experiment 1. To determine the effect of the rate of rotation on the output of the mill. The rate of rotation was varied from 10 to 20 revolutions per minute. The output was found to be proportional to the rate of rotation.

The results of the experiment show that the output of the mill is proportional to the rate of rotation. This is in accordance with the theory of the mill.

EXPERIMENTAL MILLING



EXPERIMENTAL BOILER,

WOOLWICH YARD.

Scale $\frac{3}{4}$ inch to 1 foot.

Area of Fire Grate 19.75 Square feet or 2848 Square inches.

D^o over Bridges _____ 660 or $4\frac{1}{3}$ of Fire Grate.

D^o of Flue _____ 741 or $3\frac{1}{4}$ of D^o .

D^o of Chimney _____ 1017 or $2\frac{1}{8}$ of D^o .

Heating Surface of Fire place _____ 53.75 Square feet.

D^o _____ of Top and Sides of Flues 38.5

Total Heating Surface 438.75

Heating Surface to 1 foot of Grate 22.1

Cubic contents of Fire places over the bars & before the Bridges 34 ft³

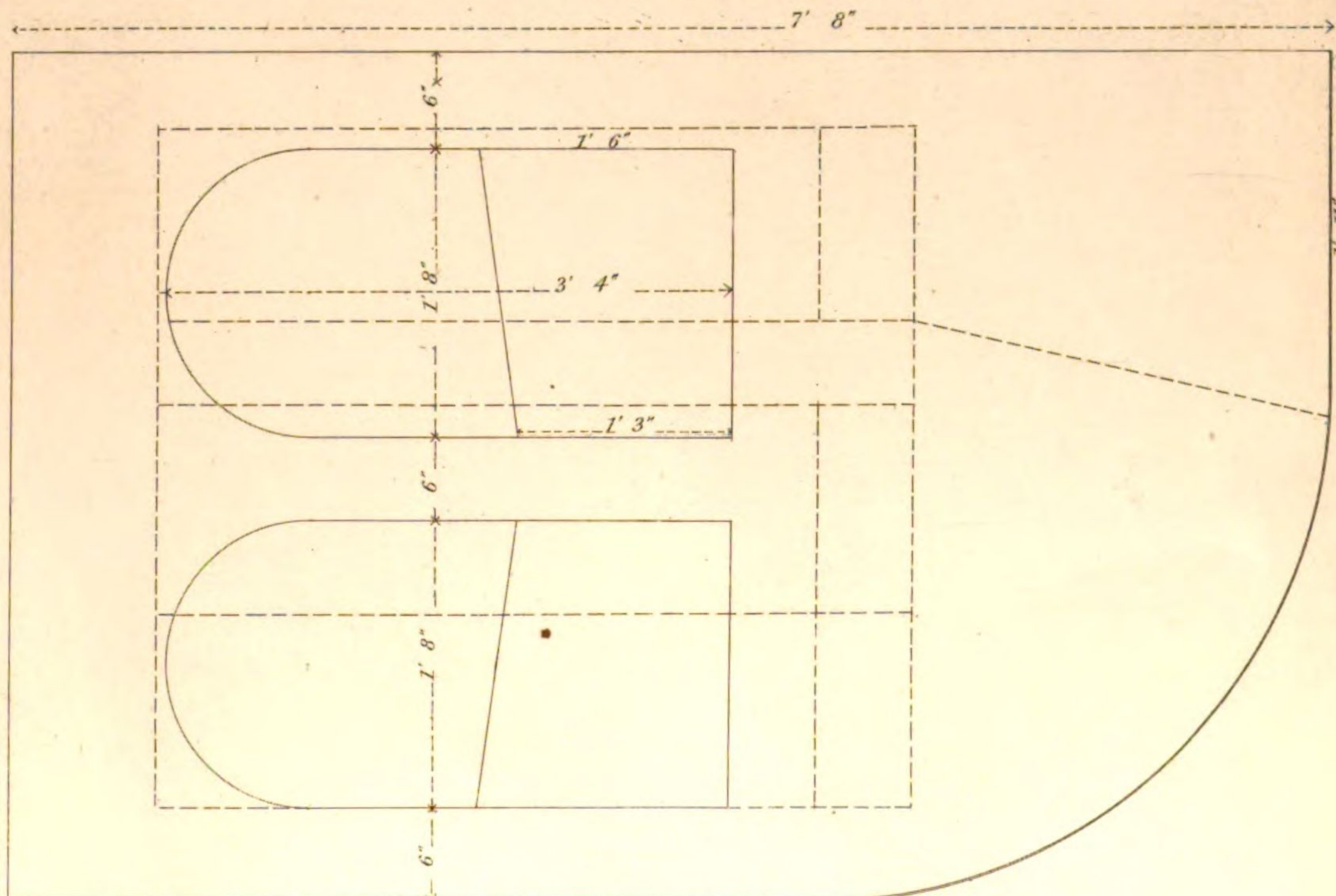
D^o _____ of Water Spaces _____ 370 feet.

D^o _____ of Steam D^o _____ 116 .

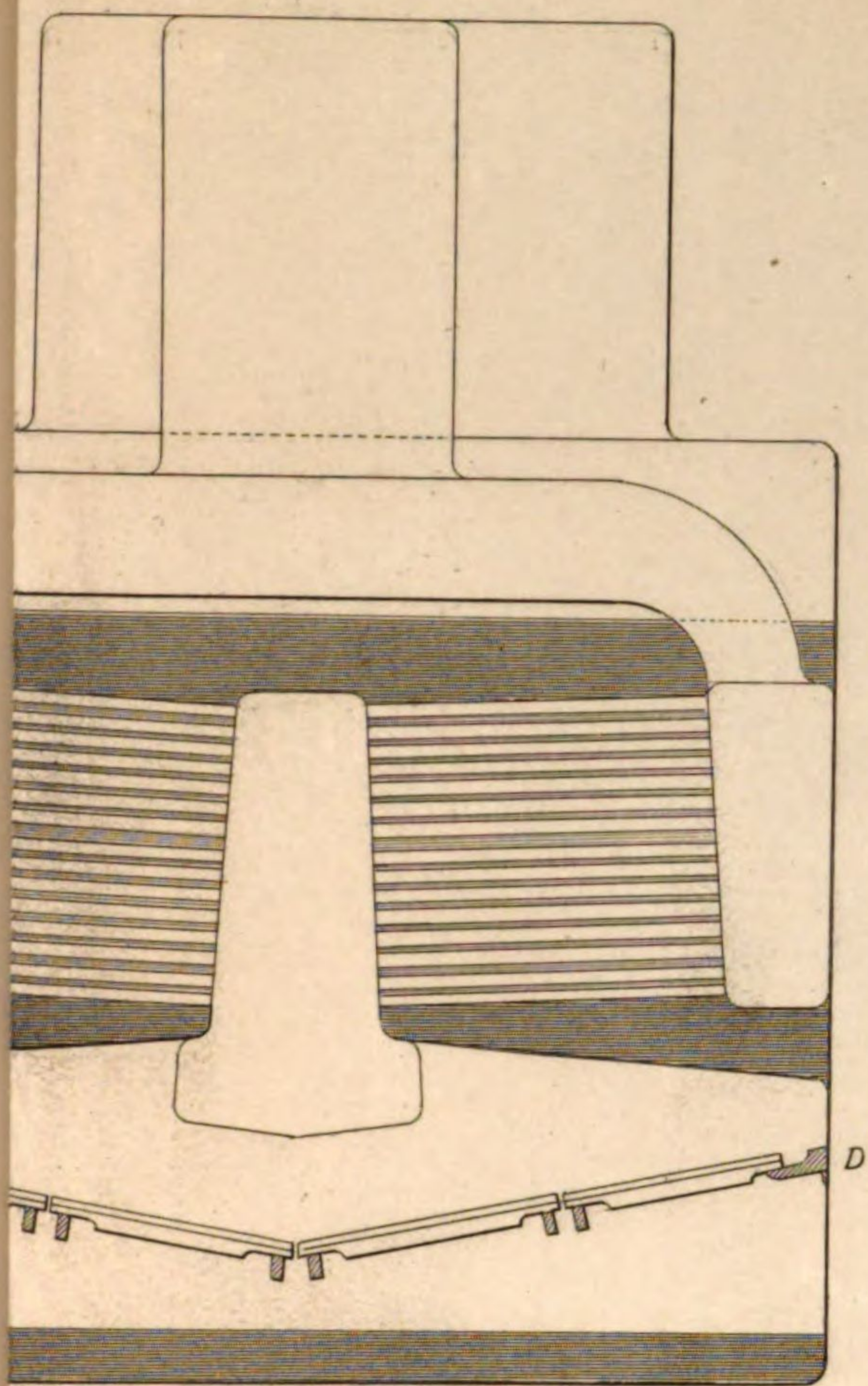
Height of Chimney above the level of Fire 29 feet.

The Boiler was formerly in H.M.S. "Lightning," of 100 Horse Power, by Maudsley & Field, and formed one half the set, or represented 50 Horse Power, at a time when the pressure on the Safety Valve did not exceed $2\frac{1}{2}$ lbs. per square inch.

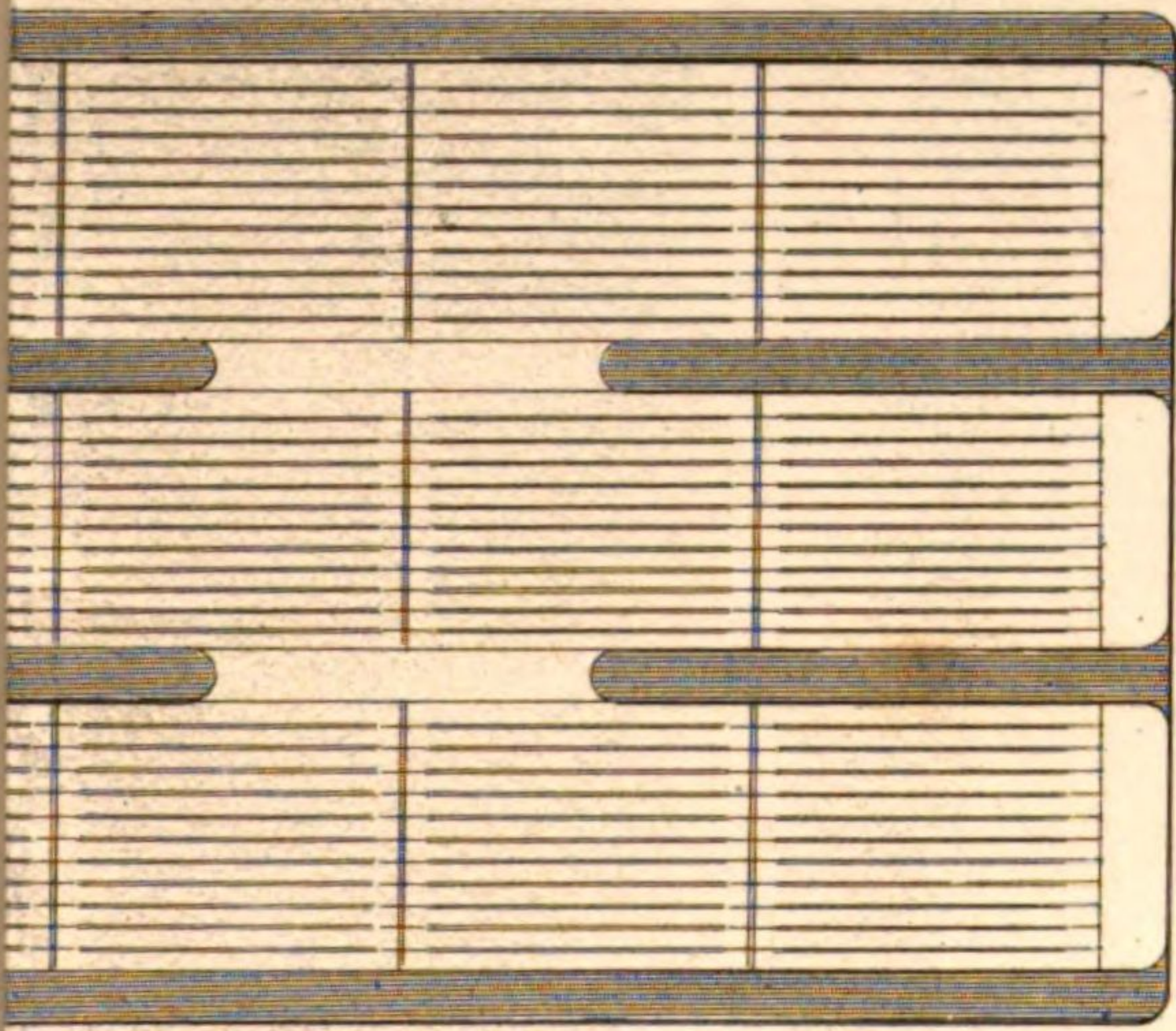
FRONT ELEVATION



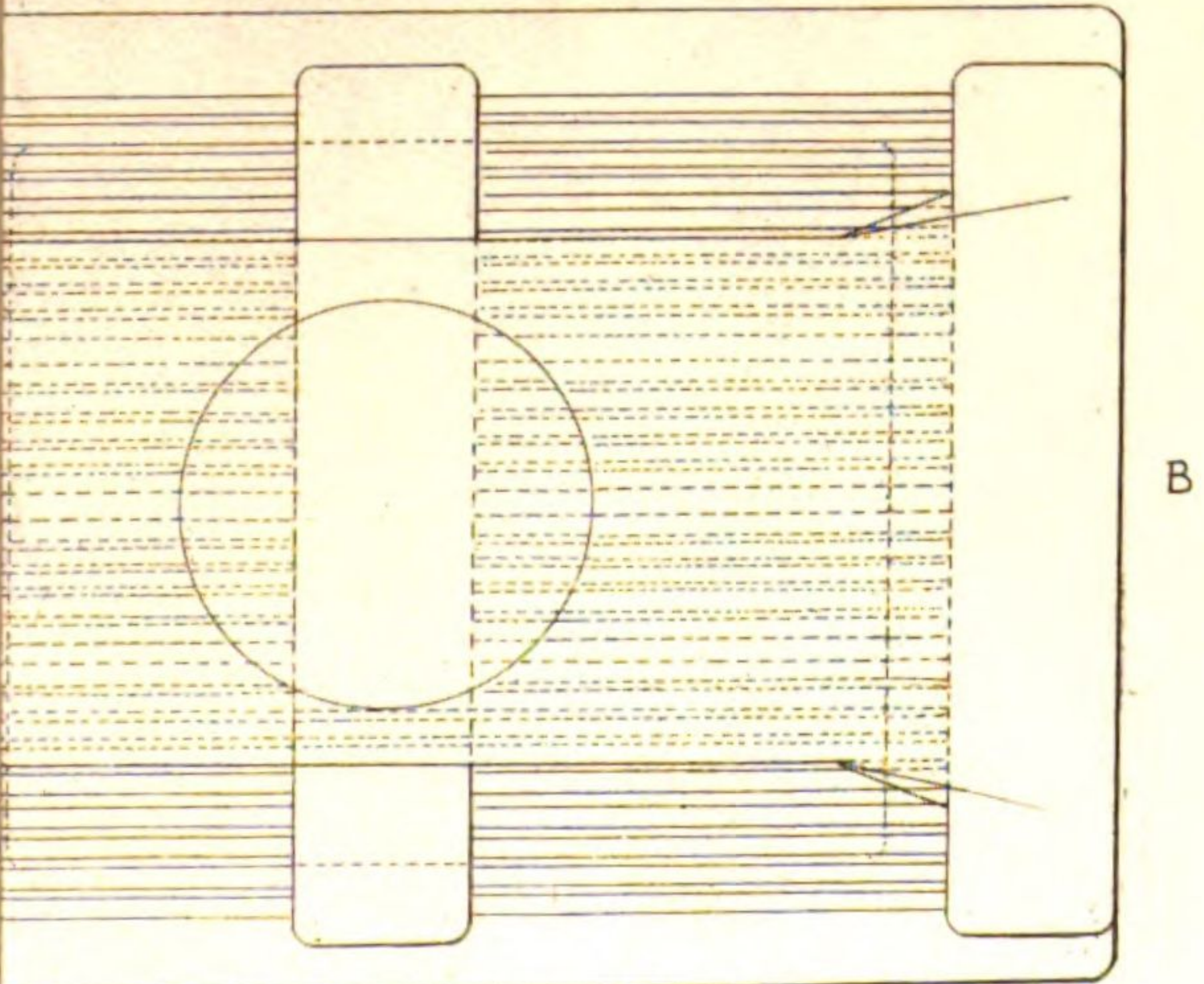
Longitudinal Section on A. B.

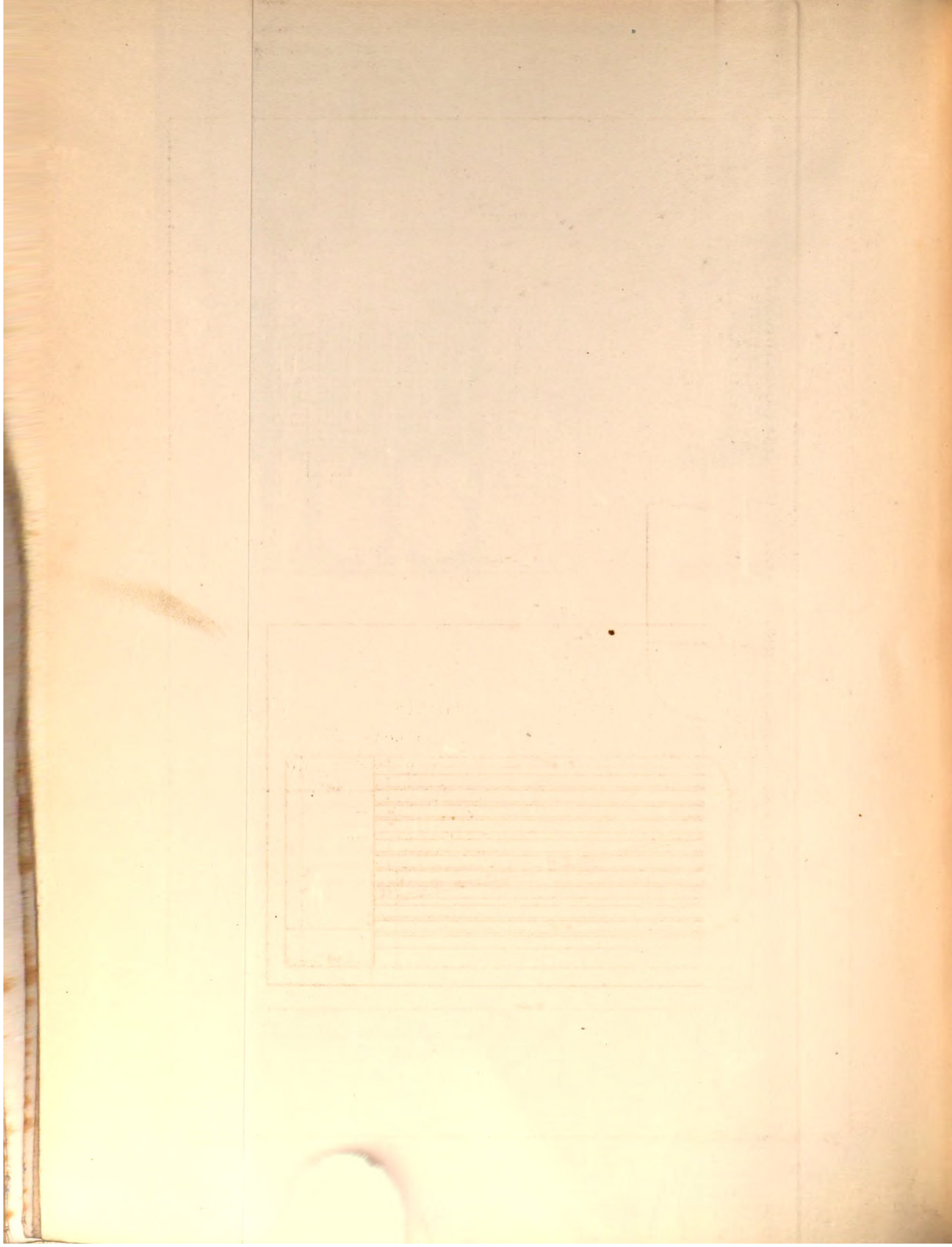


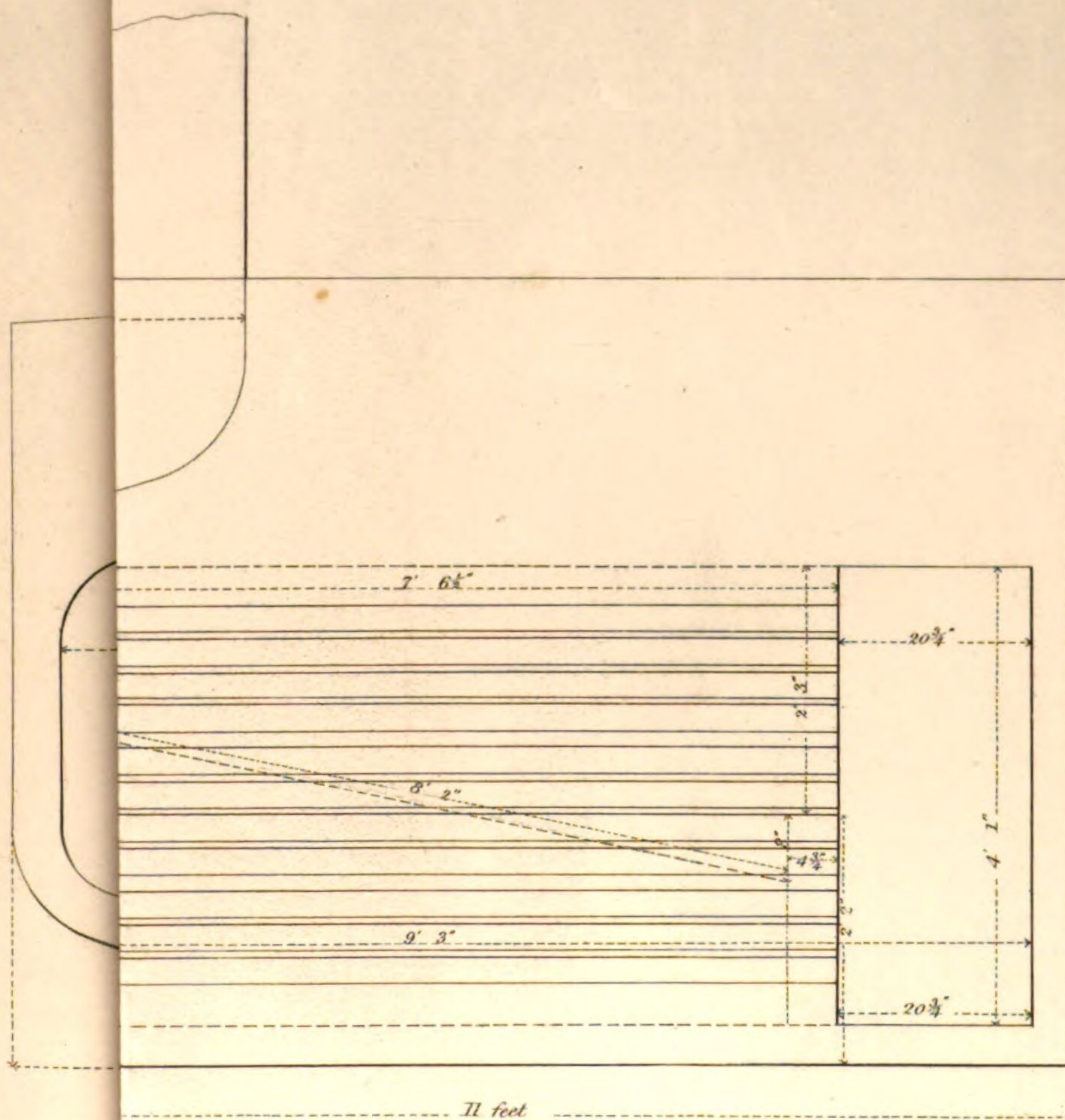
Horizontal Section on C. D.

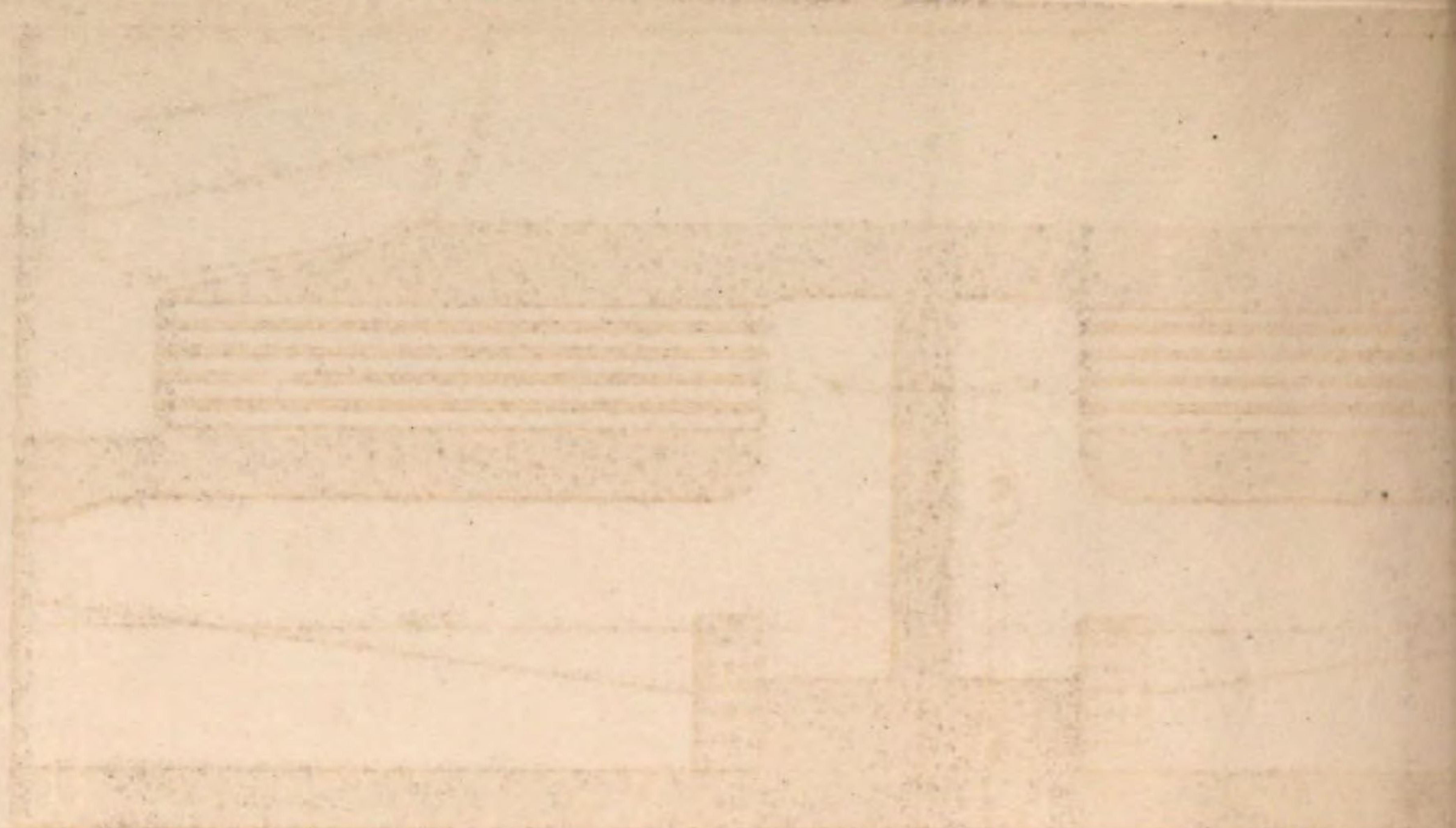


Passage for inspection and repairs.









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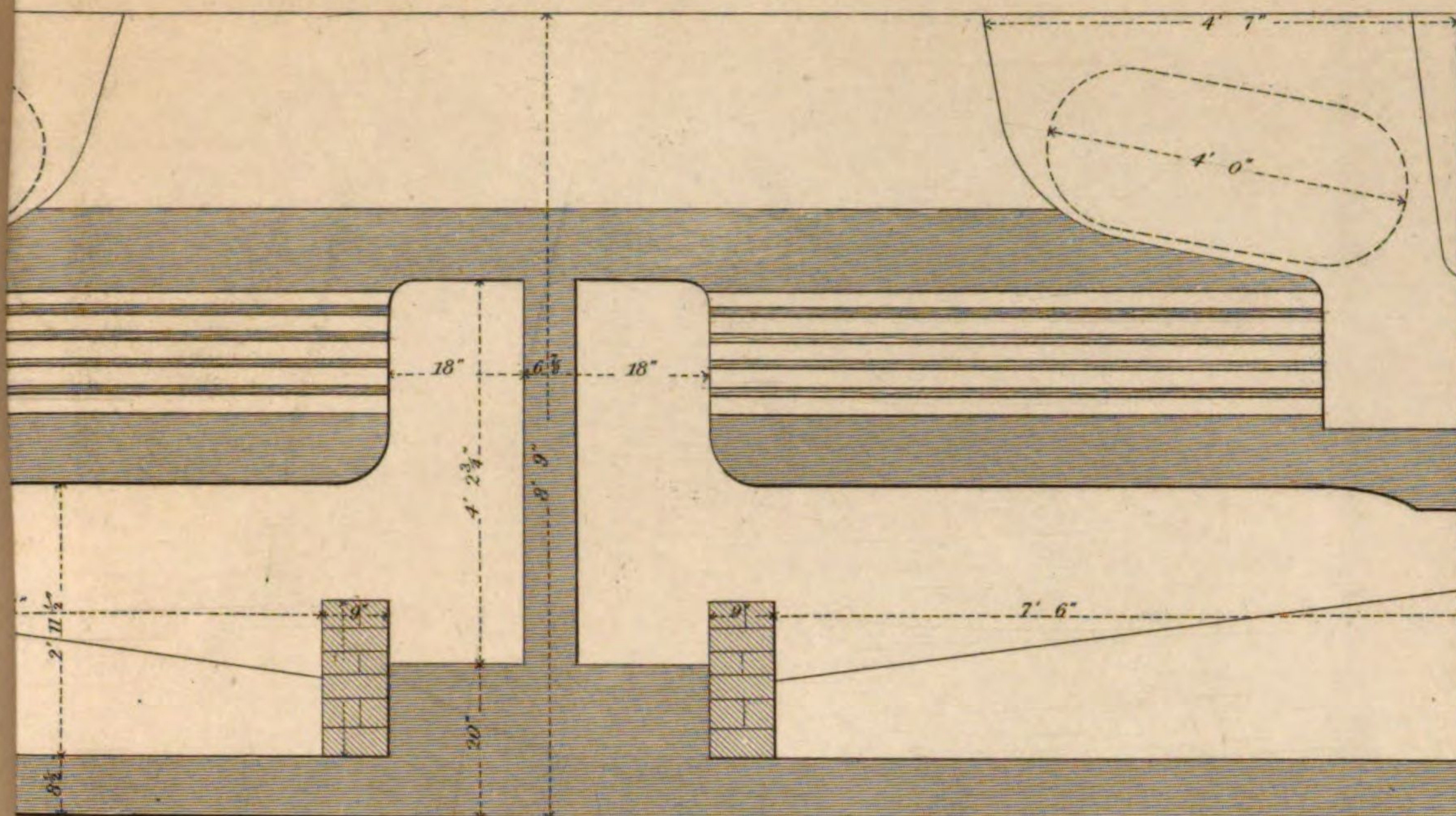
ASTOR LENOX TILDEN FOUNDATION

500 N. 5TH ST. NEW YORK, N. Y.

1897

THE NEW YORK PUBLIC LIBRARY
ASTOR LENOX TILDEN FOUNDATION
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1897

LONGITUDINAL SECTION



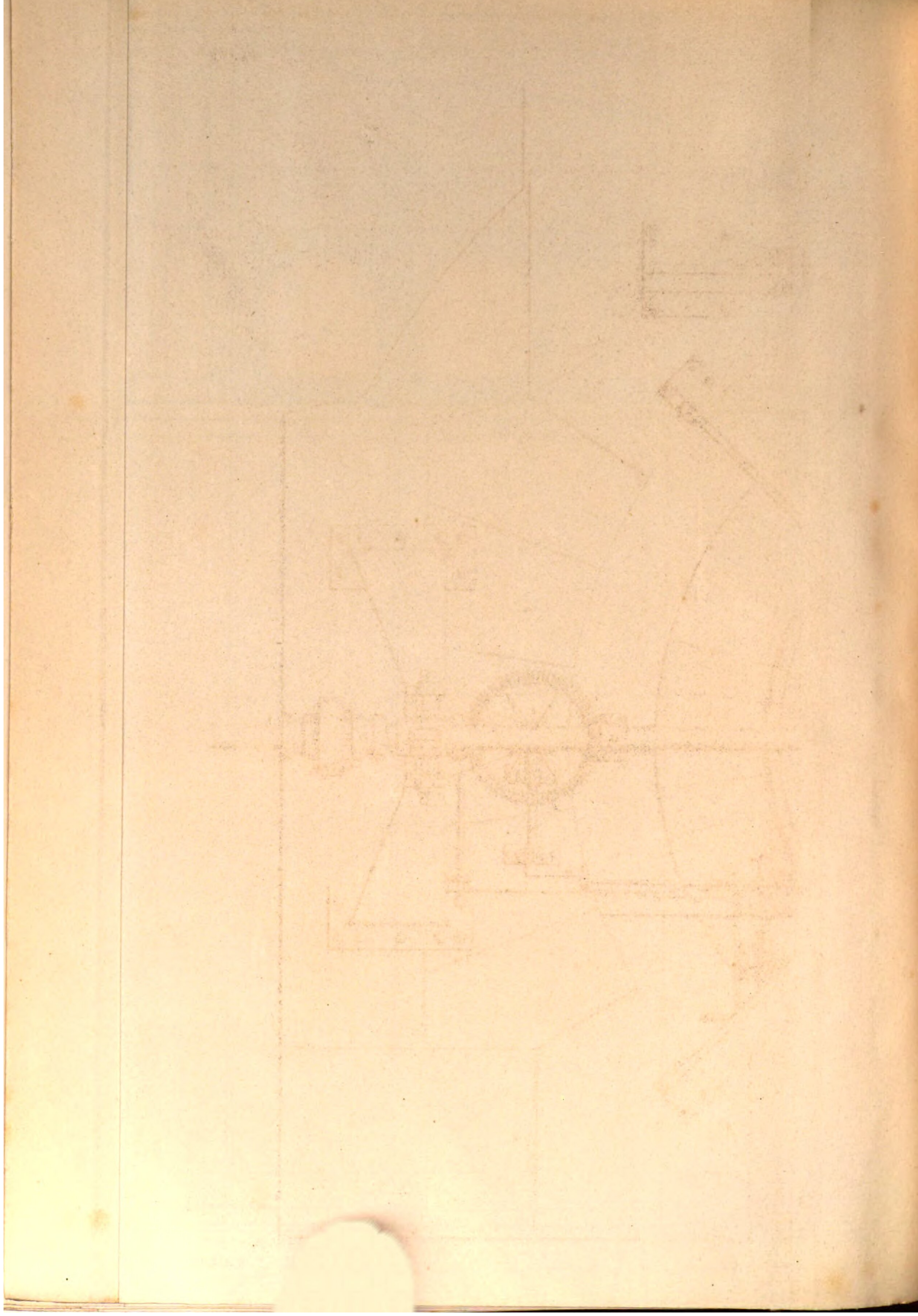
BOILERS OF THE SAMSON,

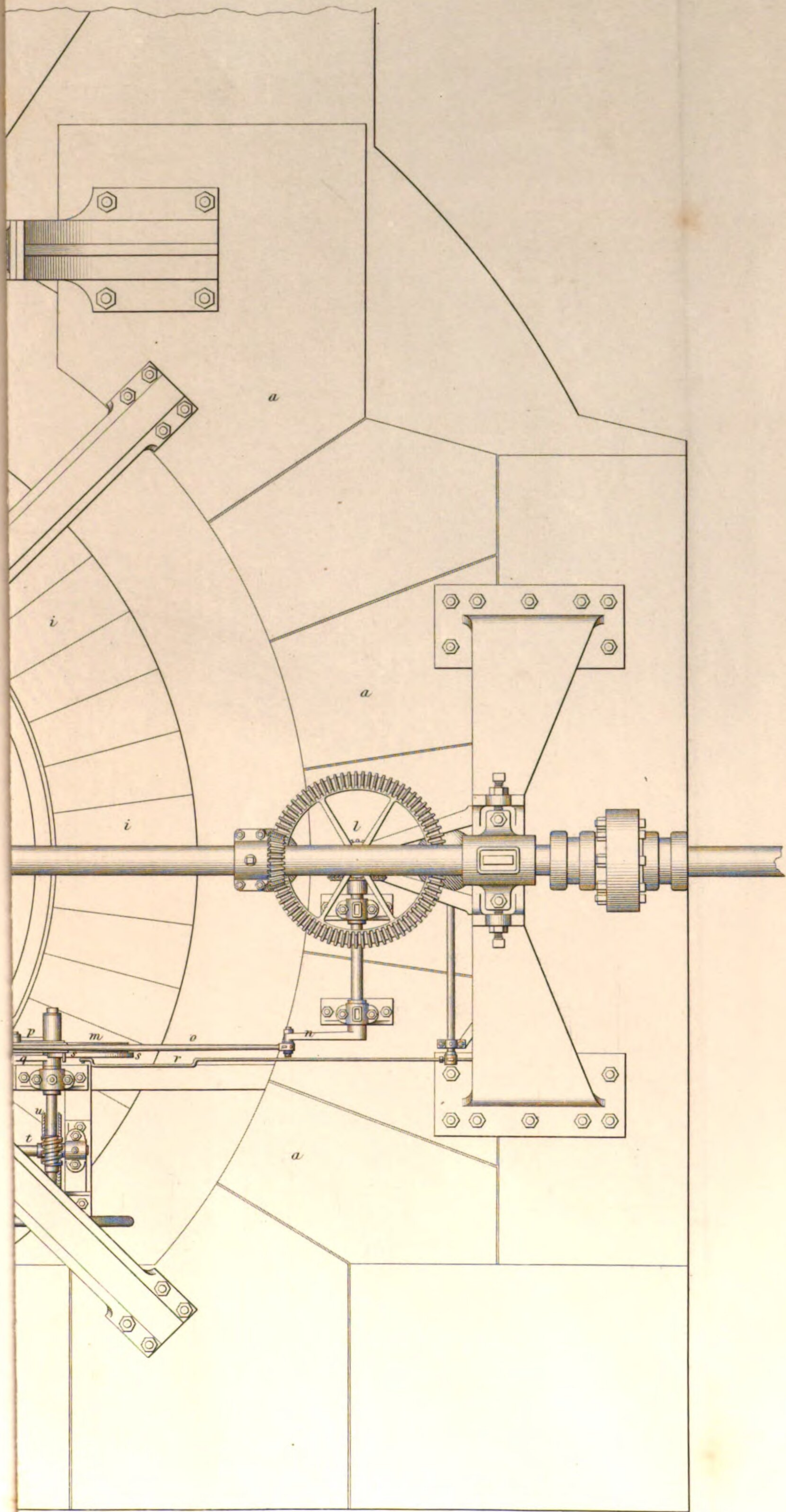
450 H. P.

Scale $\frac{1}{8}$ of an inch = 1 foot.

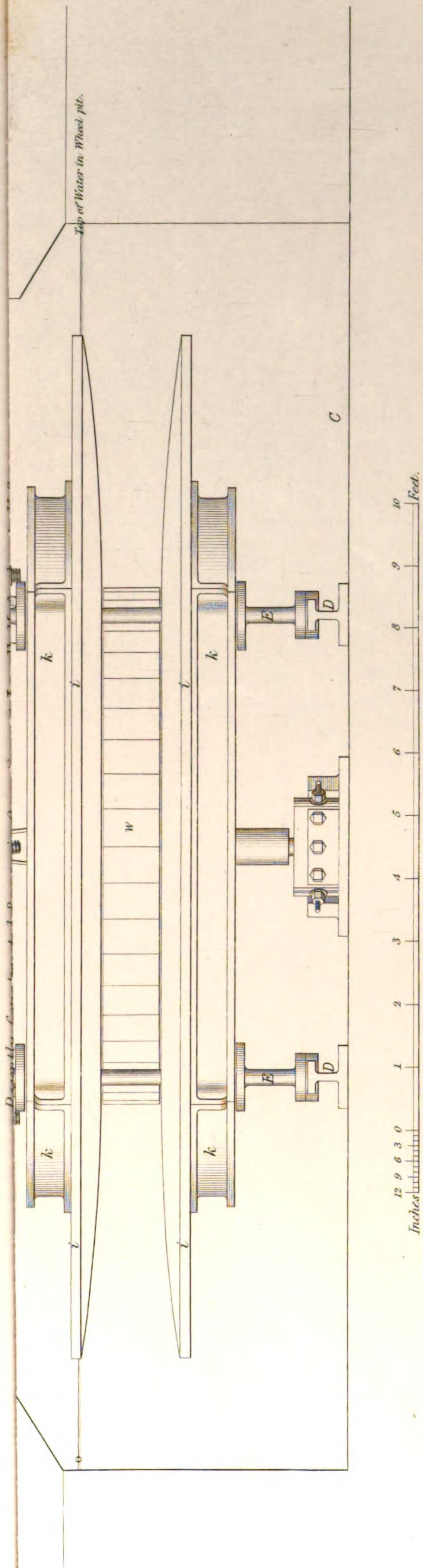
made at Woolwich, 1849.

Cubic bulk of Boilers 5145.0
 Heating Surface in Tubes $\frac{5270.504}{450} = 11.71$ Sq. ft. P.H.P.
 D^o Furnaces 903.
 Total Heating Surface $\frac{6173.504}{450} = 13.71$ Sq. ft. P.H.P.
 Grate Surface $\frac{238}{450} = 528$ Sq. ft. P.H.P.
 N^o of Tubes 1208. Length 6' 8" Outside diameter 2 1/2 inches.
 Water Surface 438.440 Sq. ft. = 9743 Sq. ft. P.H.P.
 Steam Room 993.376 Cubic ft. = 2.207 Cubic ft. P.H.P.
 Weight of Water 62 Tons.
 Content of Boilers 5035.5 Cubic feet = 11.19 Cubic ft. P.H.P.



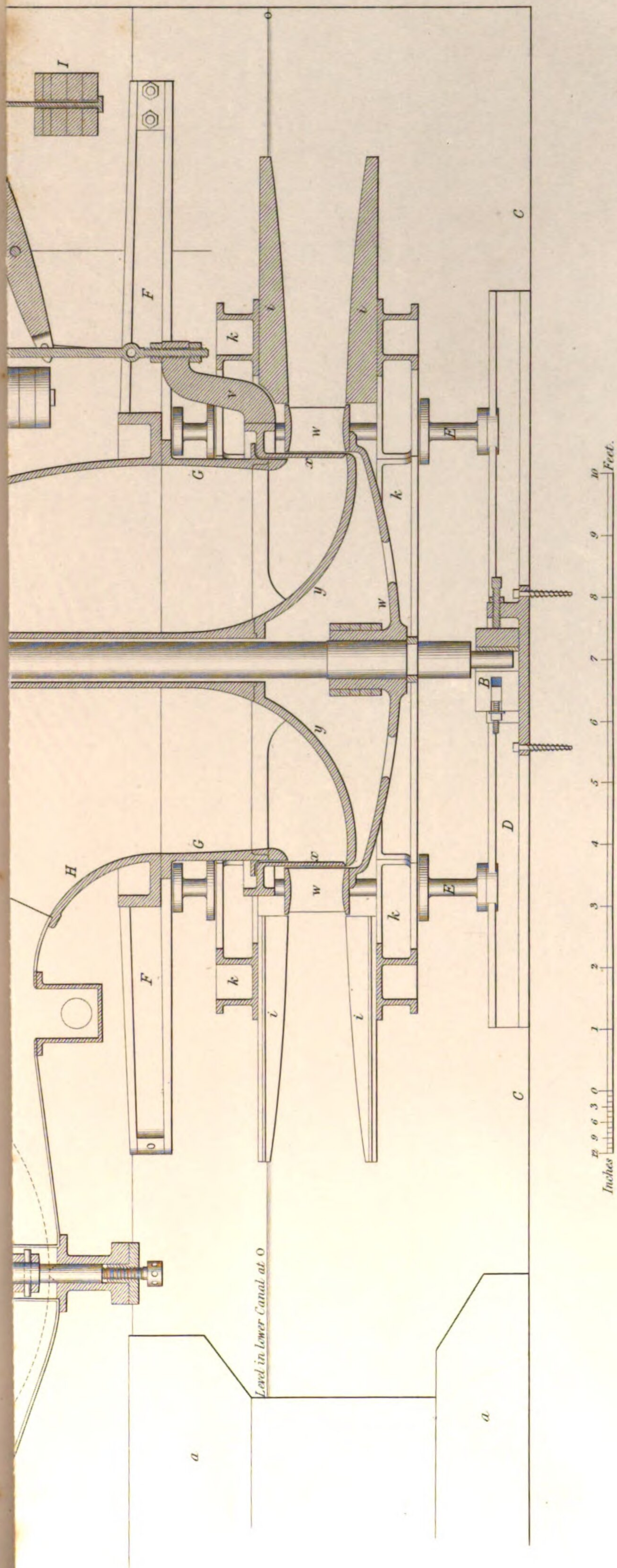


TURBINE WATER WHEEL.



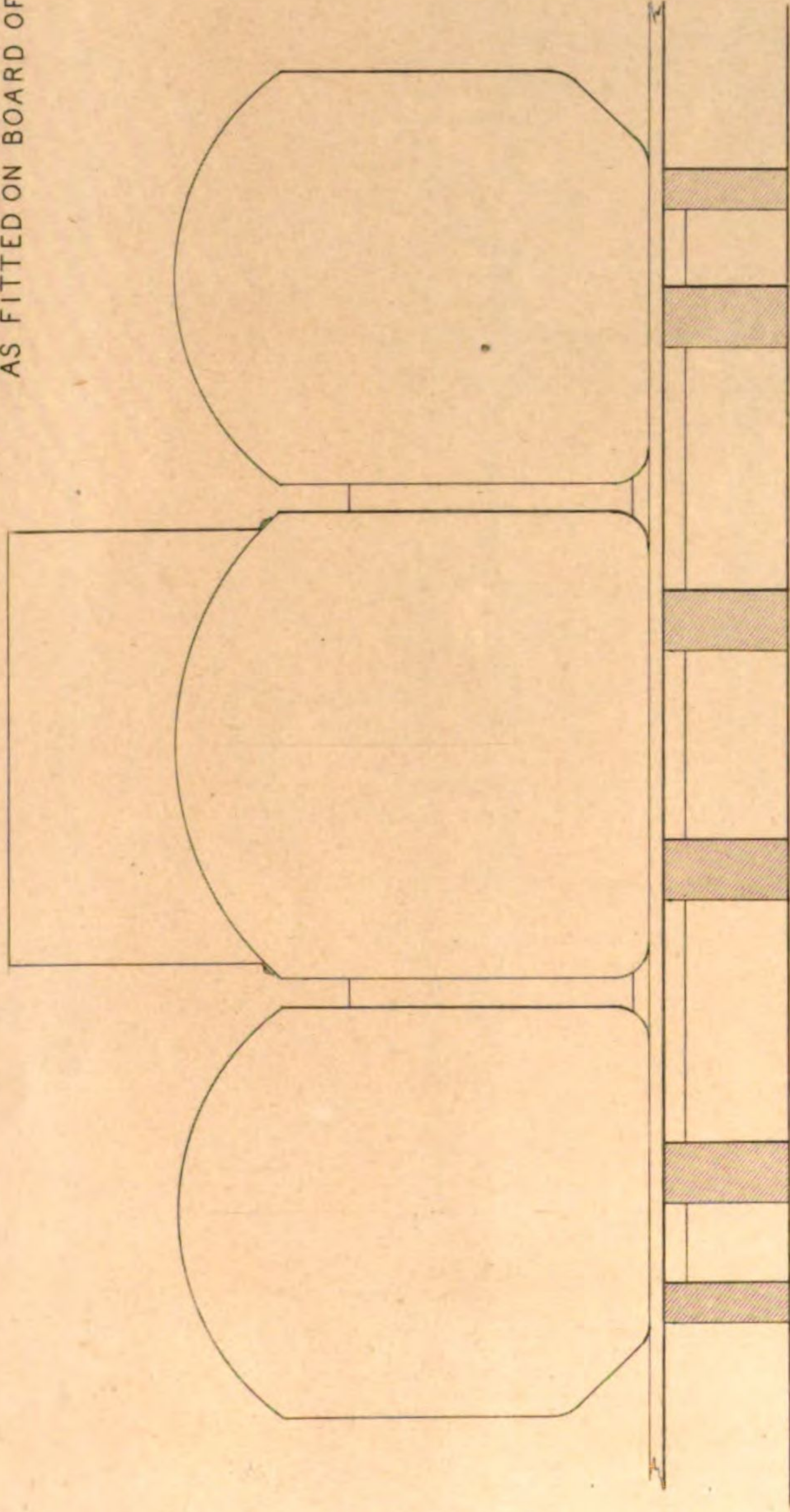
London, John Weale, 1852.

W. A. Bever, Sc.

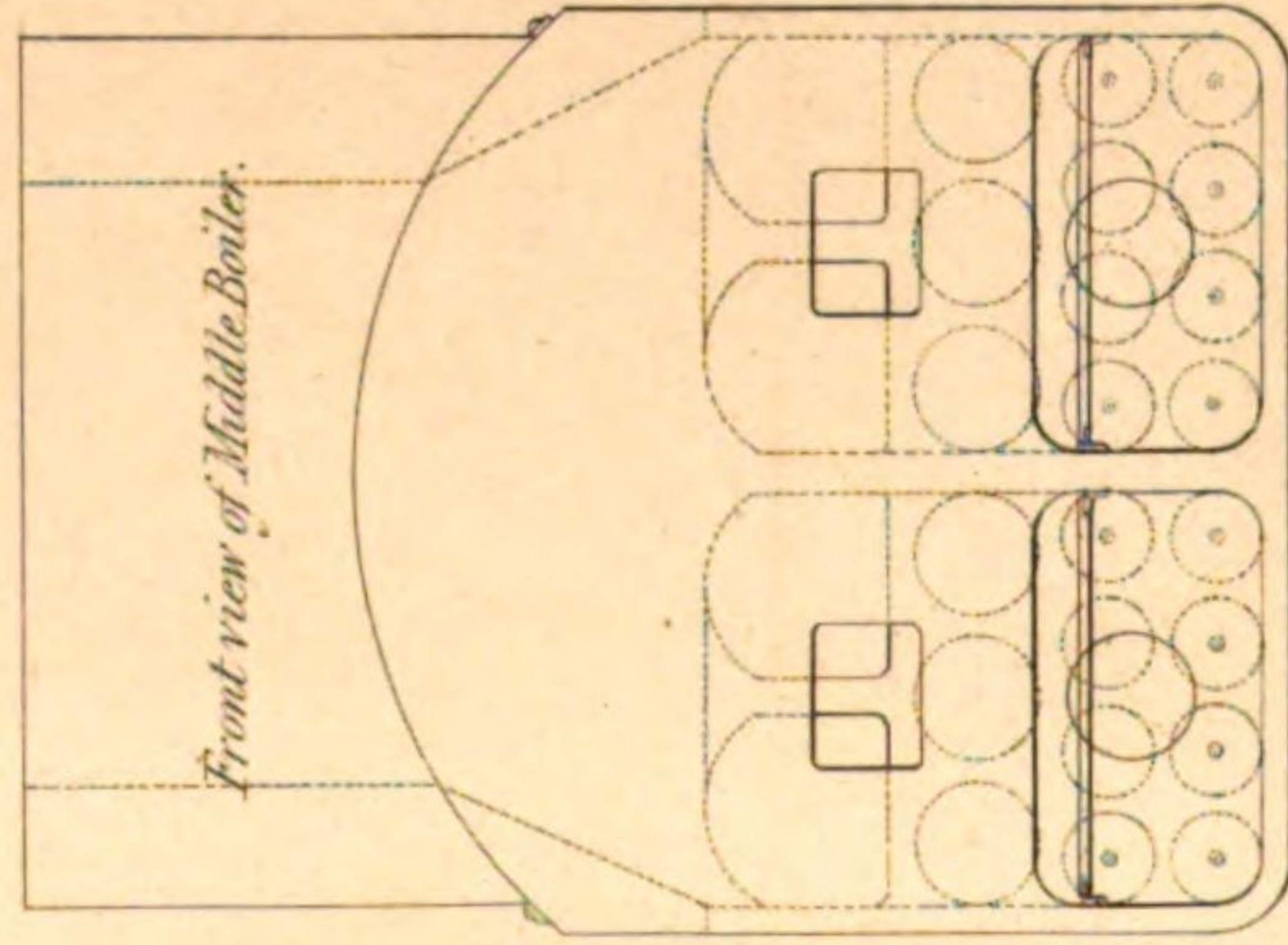
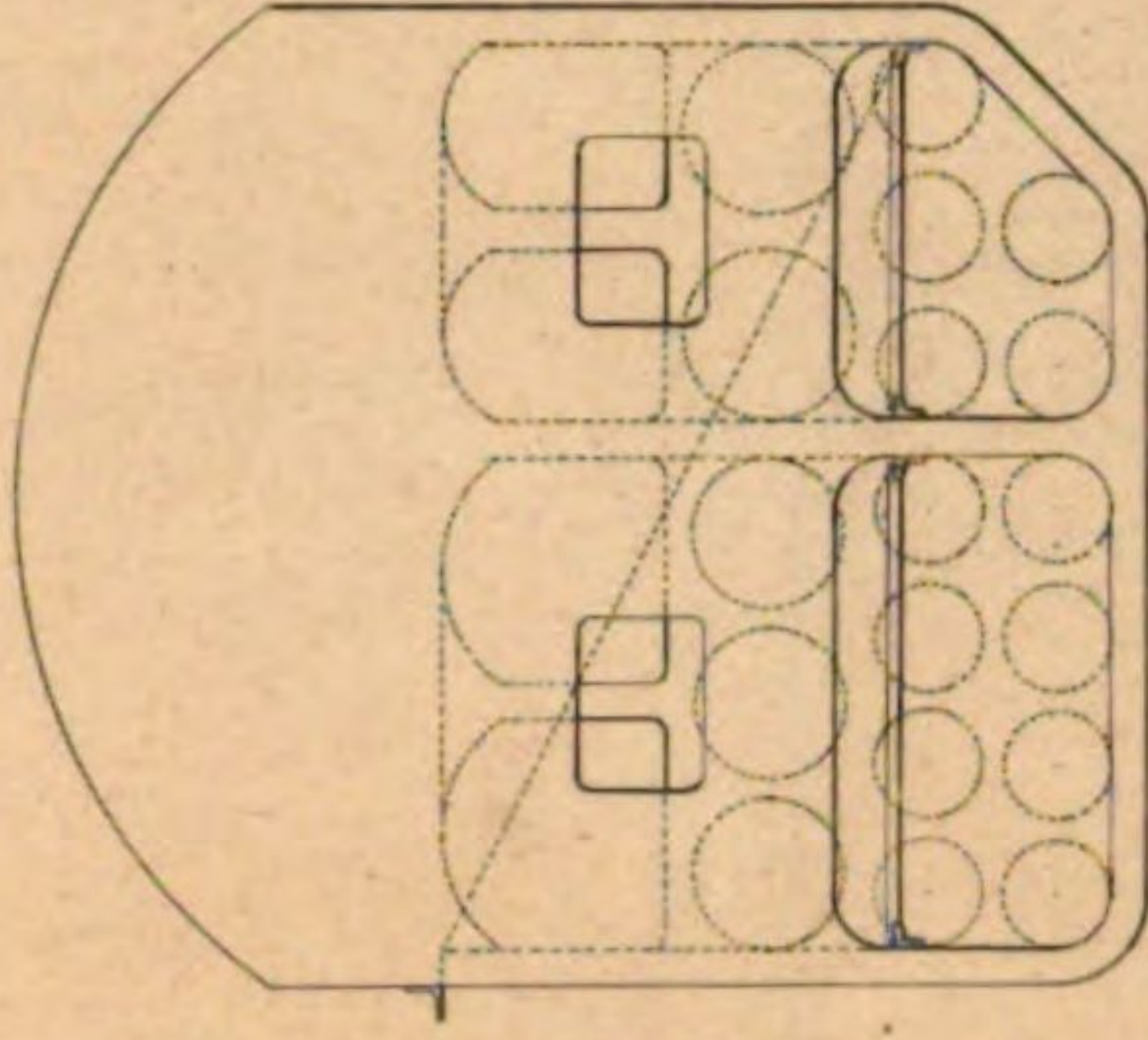


AMERICAN MARINE BOILERS,

Designed & Executed by C.W. Copeland Esq. Engineer of New York.
AS FITTED ON BOARD OF THE AMERICAN PACKETS.

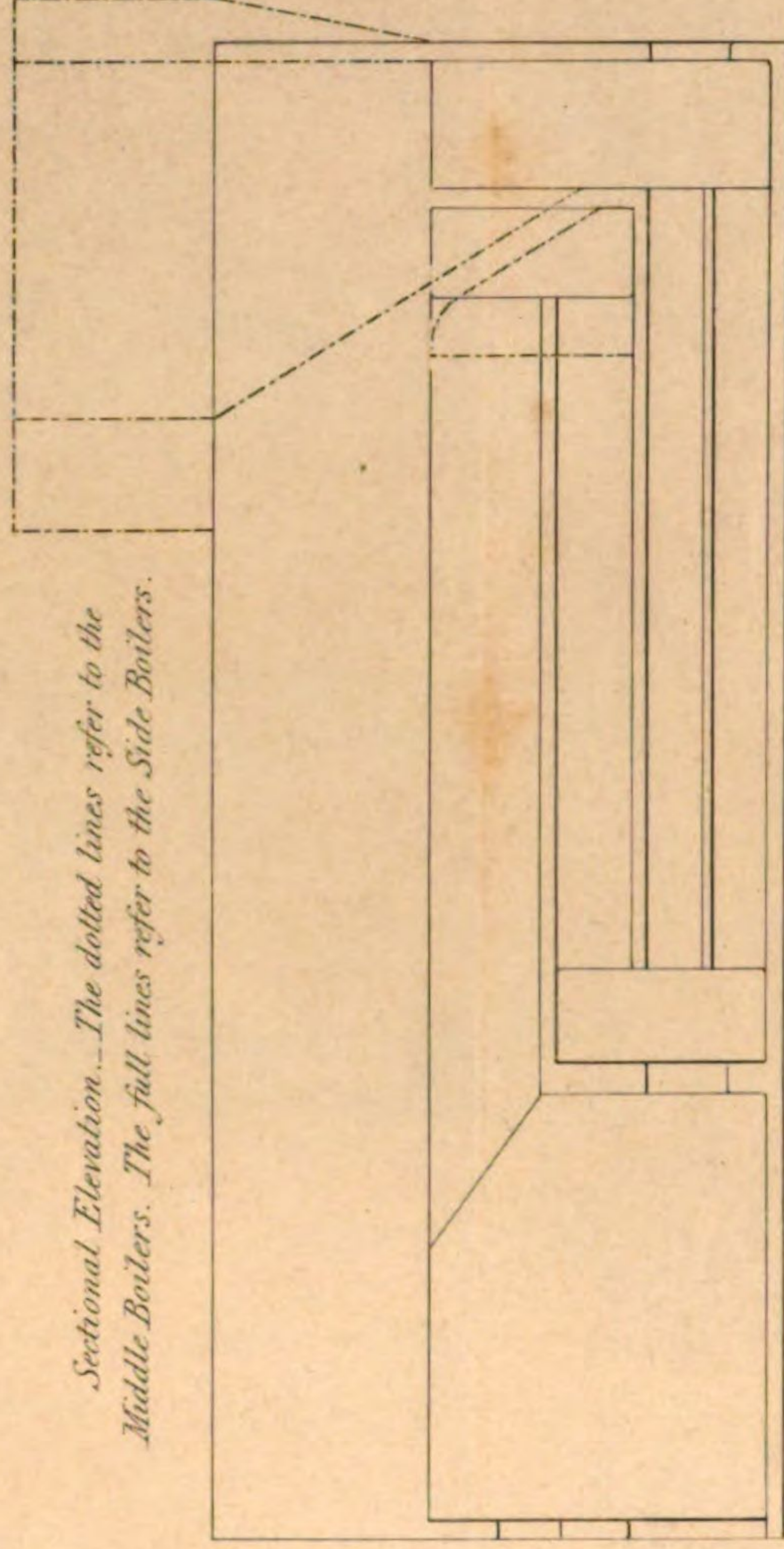


Front view of Side Boilers.

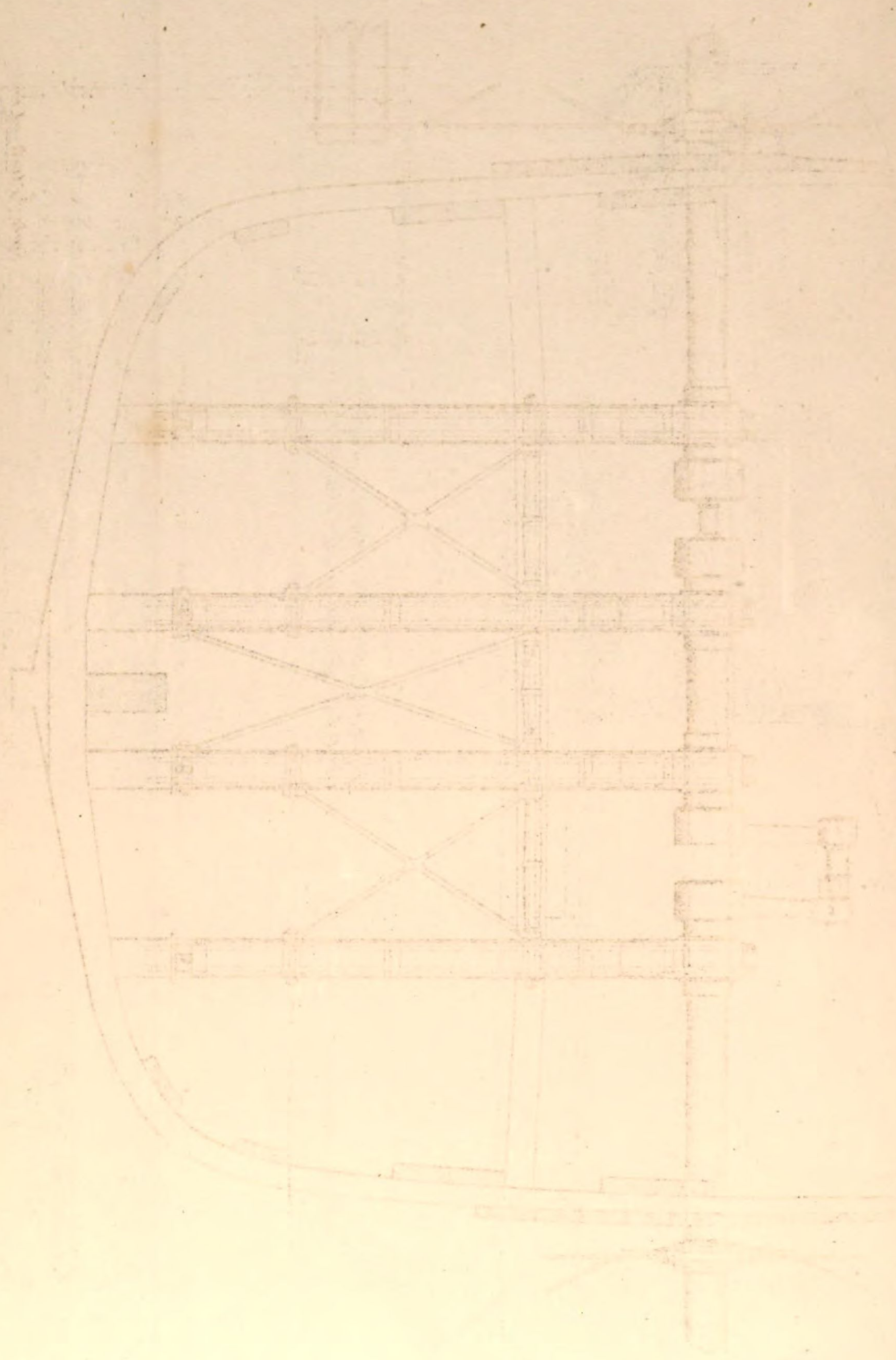


Front view of Middle Boiler.

Sectional Elevation... The dotted lines refer to the Middle Boilers. The full lines refer to the Side Boilers.

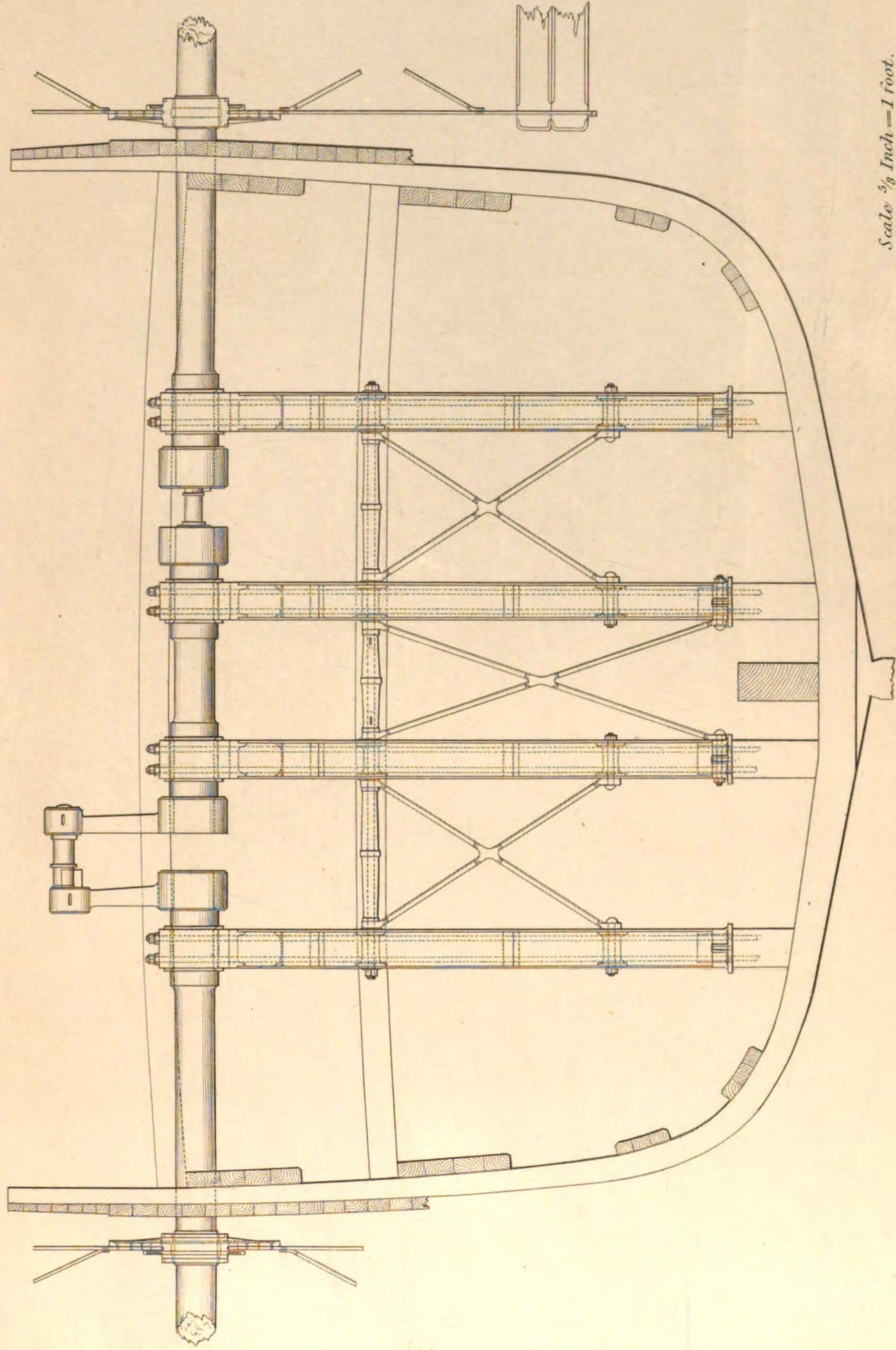


Scale $\frac{1}{8}$ in = 1 foot.



SECTION OF THE HULL OF THE STEAMER "ALBATROSS" SHOWING THE POSITION OF THE MAIN MAST AND FUNNEL

MIDSHIP SECTION OF THE HULL OF THE STEAM PACKET "PACIFIC" NEW YORK & LIVERPOOL, LINE.

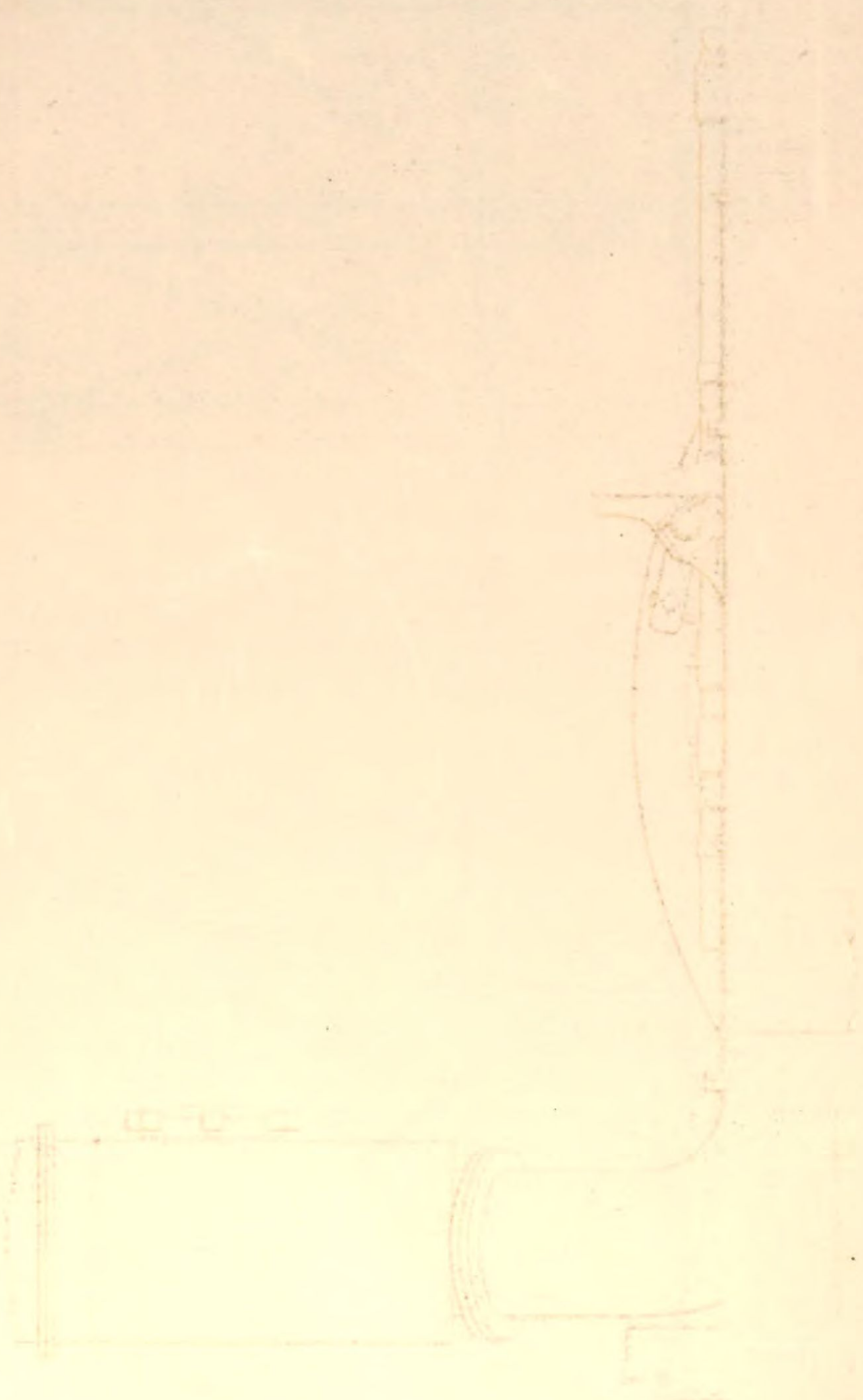


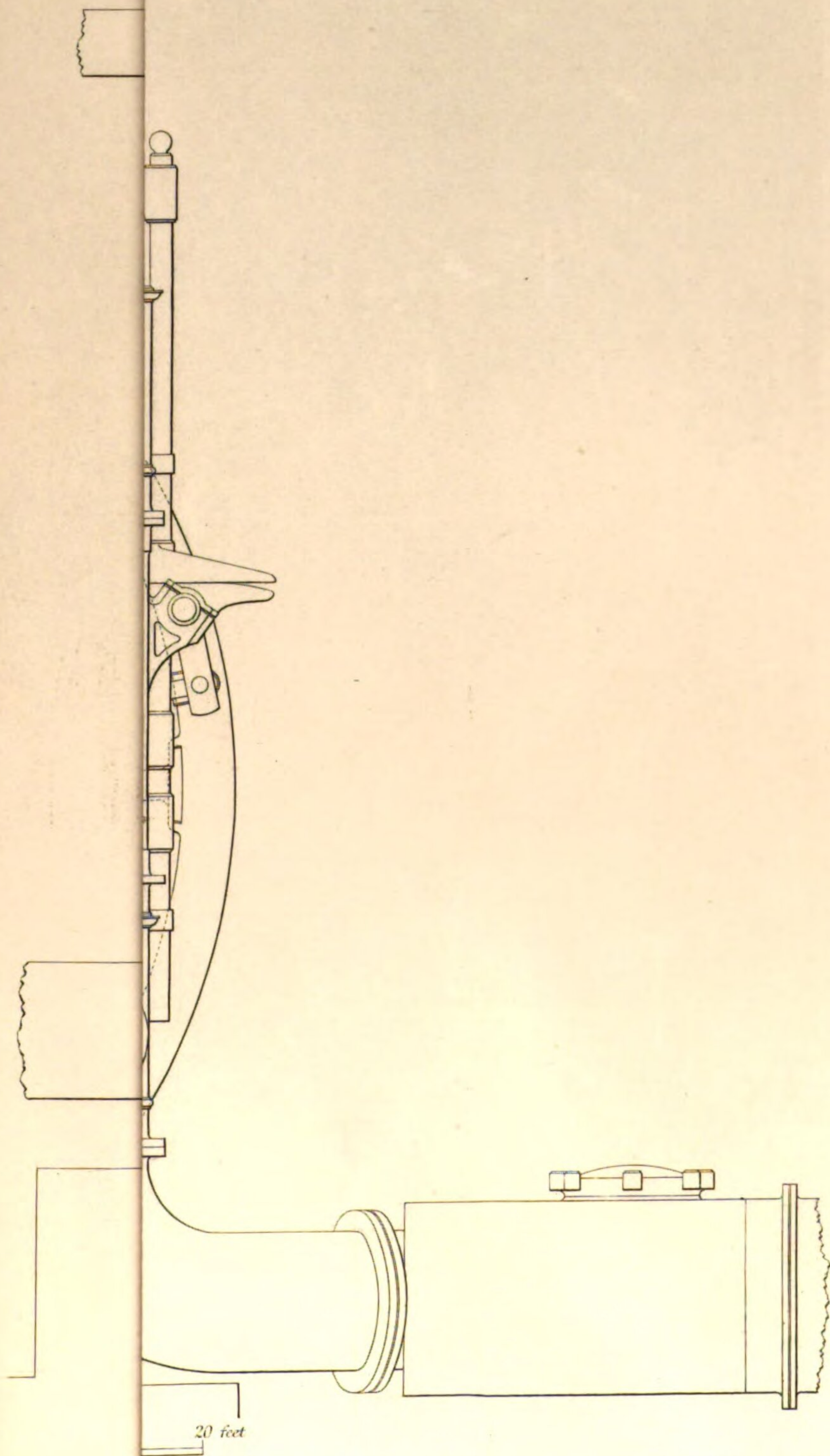
Scale $\frac{5}{8}$ Inch = 1 foot.

Chas. W. Copeland del.^t

Published by John Weale, 59 High Holborn, London, March 1, 1852.

J. H. Le Keux sc.

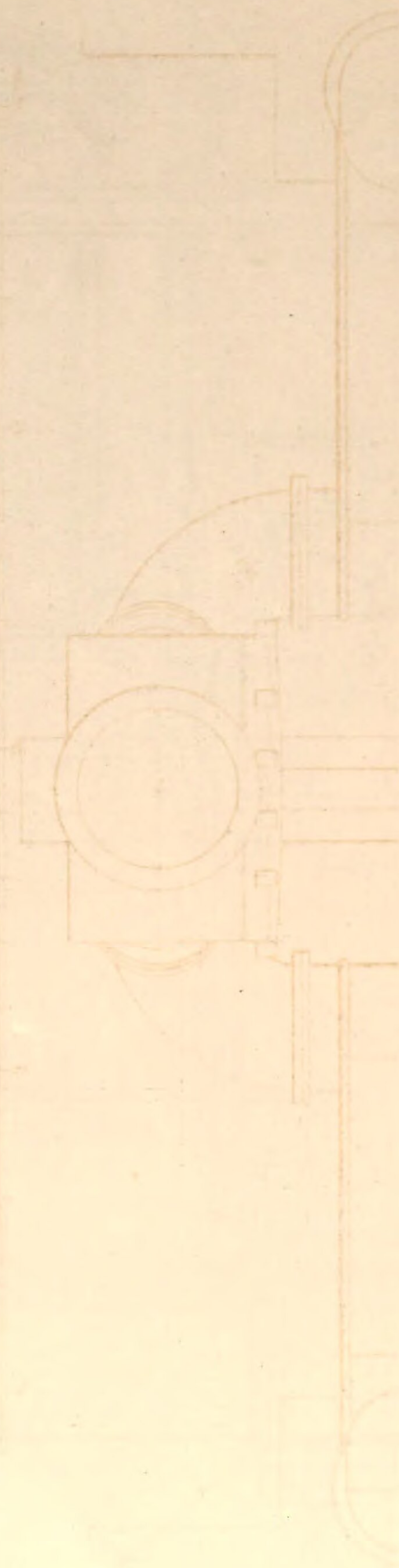


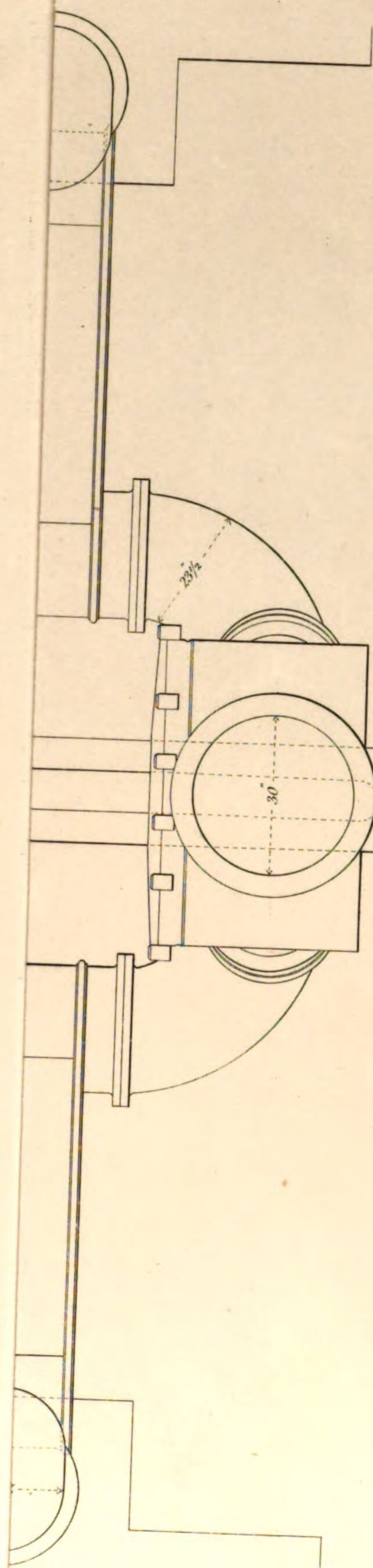


Top view of the

7500 North view of the

7500 North view of the

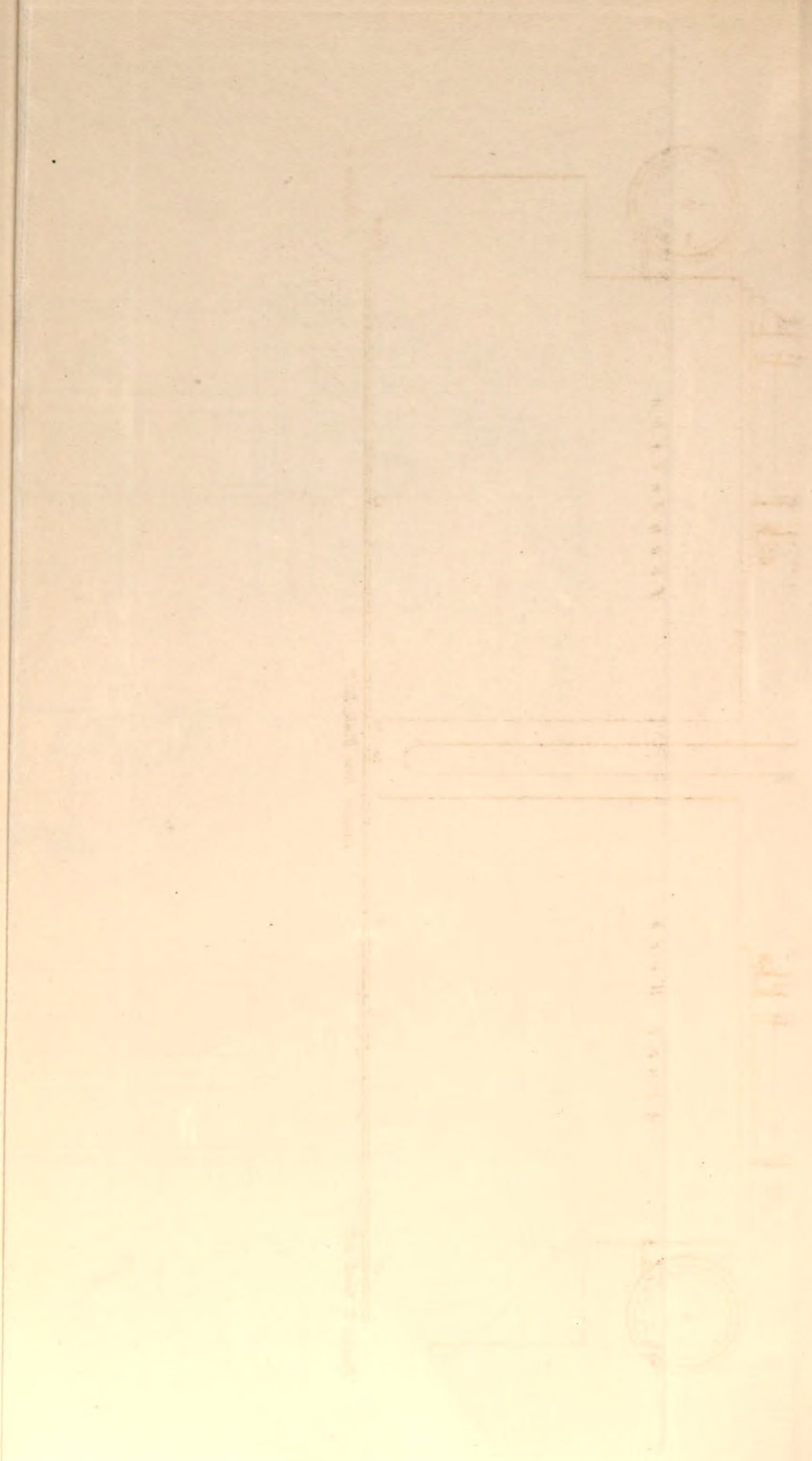


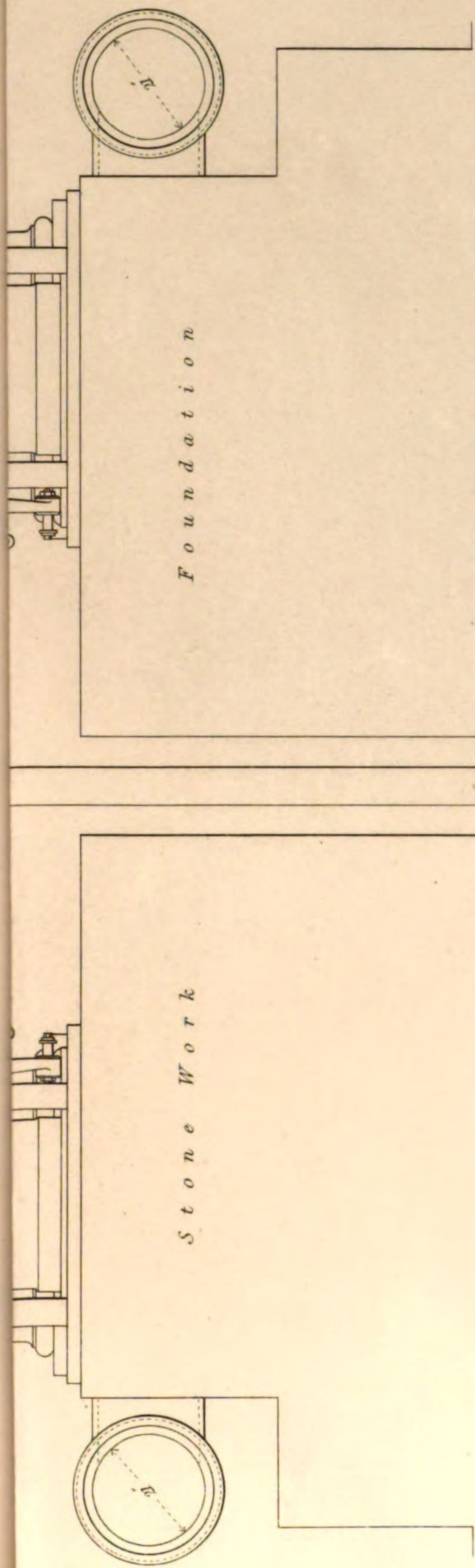


Erastus W. Smith, del.

London: John Weale, 1852.

G. Gladwin, sculp.





20 feet

15

10

5

0

Erastus W. Smith, del.

London: John Weale, 1852.

G. Gladwin, sc.

DESCRIPTION

OF

THE DISC ENGINE

APPLIED AS A MARINE ENGINE TO DRIVE THE SCREW-PROPELLER.

BY GEORGE RENNIE, ESQ., F.R.S., C.E., &c.

ON THE DISC ENGINE.

THE engravings represent a 27-inch disc engine, applied as a marine engine to drive the screw-propeller, for which purpose it possesses many advantages. Before enumerating these, it will perhaps be as well to describe the origin, construction, and action of the engine.

This engine appears to have been first invented by Messrs. Dakeyne, merchants, at Derby, who, in 1830, obtained a patent for it as an hydraulic machine for producing motive power,—capable also of being worked by steam. There is no record of any engines having been made under their patent. One engine, however, may have been made as an experiment, but it could not have succeeded on account of the many complicated parts which were introduced to meet imaginary difficulties.

In 1836, Henry Davies and William Taylor took out a patent for a steam engine similar to Dakeyne's in principle, but differing in its action, inasmuch as the crank was stationary and the cylinder revolved.

Henry Davies took out several patents subsequently, the last being dated 1844. Under these patents, a large number of engines were made, many of which are still at work in various parts of the kingdom.

In 1845, a patent for Improvements in the Disc Engine was taken out by George Daniel Bishopp, under whose patent about twenty engines have already been constructed.

In 1849, a patent was also taken out by Bryan Donkin and Wm. Farey, for Improvements in the Disc Engine, but most of their modifications had been previously included in Davies's patents.

We will now describe the construction of the disc engine.

The steam chamber (which we will call the '*cylinder*' as usual) is bored spherically, and is a zone of a hollow sphere, the ends of which are placed in a vertical position, the cylinder being in a horizontal position.

To the ends of this zone covers are fitted; the internal parts of which

covers are frustums of hollow cones, of such an angle that the apex of each cone would not reach the centre of the spherical chamber. In the small ends of these conical frustums spherical seats are bored, having the same centre as the spherical chamber.

At the bottom between the two covers or 'cones,' and at right angles with them, *i. e.* longitudinally with the cylinder, is fixed a thick plate or 'partition,' which is let into grooves in the cones and in the cylinder, the upper edge being fitted with metallic packing curved to the same radius and from the same centre as the spherical seats in the cones.

The piston or 'disc' consists of a circular plate of such thickness that the two flat sides will respectively touch the two cones. This disc is either cast with or attached to a spherical boss or 'ball' concentric with it, which ball fits the spherical seat in the cones and partition. A piece is cut out of the disc to allow the partition to pass through it. The periphery of the disc is fitted with metallic packing rings, much in the same way as the pistons of other engines. Also the seats in the cones are fitted with metallic glands to carry the ball of the disc, and with hemp packing to render the seat steam-tight.

In the ball or boss of the disc is keyed an arm or 'diagonal shaft' passing through the ends of the cones: one end of this arm enters a brass bush or block fitted in a crank or pulley fixed on the screw-propeller shaft, to which it gives motion; the steam causing the disc to roll on and between the two cones, and consequently the end of the diagonal shaft to describe a circle. The only parts, however, which revolve, are the crank and the screw-shaft, the disc being prevented from rotating by the partition.

The steam ports are on one side of the partition, and the exhaust port on the other side, and the engine works at full pressure without any valves whatever, the disc itself shutting off the steam from the induction and admitting it to the eduction port. Expansion valves are, however, now generally used with this engine, which offers admirable facilities for their use.

The advantages gained by the use of this engine to drive the screw-propeller are as follows:

The disc engine acts with a uniform force on the crank of the propeller shaft continuously in the direction of the motion of the crank, and having no dead points nor a reciprocating motion, the engine runs with ease at the same speed as the propeller.

The engine is lighter and occupies less space than the ordinary engines, and the consumption of fuel has been proved by numerous experiments to be less. It is also much less liable to derangement, for no water can get jammed in the

cylinder; and as the driving arm, before mentioned, enters a brass bush forming a ball and socket joint in the crank, no twisting strain can be thrown on the latter, and neither the cylinder covers, bottoms, nor the cranks are liable to breakage, accidents which so often happen to other engines.

As the disc or piston rolls between the two cones, its centre of gravity remains a fixed point; and as the arm moves continuously in a circle, there is never any jumping motion in the brasses, nor do the bearings ever heat.

The disc engine also offers a facility for using the steam very expansively for marine purposes which is not possessed by any other engine, for the force of the steam on the disc being entirely resisted by the two cones, no racking strain is thrown on either the crank, the engine frame, or the vessel: also the exhaust port is always wide open, being distinct from the induction ports, and the exhaust steam has a free passage to the condenser.

There are also many other minor points of advantage which need not be enumerated here.

A large number of these engines have been at work at various mills and factories in the kingdom for years past, and all the experience necessary to make a perfect machine has been supplied by them.

The disc engine has several times been successfully applied on a small scale to drive the screw-propeller.

In 1842, a disc engine of 5-horse power was fitted in the pinnace of H. M. ship the 'Geyser,' to drive a pair of Capt. Carpenter's propellers. The pinnace was 30 feet long and 9 feet wide, and capable of carrying eight tons. Being very bluff in the bows, she was not calculated for high velocities, but power and not velocity was aimed at, the object being for the pinnace to tow the ship's boats against wind and tide into shallow harbours and rivers where an armed force might be wanted. Trials were made on the Thames in April, 1842, with the pinnace, in the presence of Sir Edward Parry, Comptroller of Her Majesty's Steam Marine, and Messrs. Ewart and Lloyd, the Government Engineers, and the result, as reported, was highly satisfactory.

The 5 H. P. disc engine with which the pinnace was fitted weighed altogether but 6 cwt., and measured 3 feet by 1 foot 6 inches, leaving ample space for a full complement of men.

During the first trial a regular speed of seven miles per hour through the water was obtained, as indicated by Massey's log, although from the unfavourable shape of the boat a wave of nearly 18 inches deep was carried before the bows. The velocity of the engine shaft was 200 revolutions per minute.

In the second trial the pinnace drew after her, at about the same rate of

speed, a regular gun-boat furnished with cannon and a complement of 50 men, with their arms and ammunition.

The engine and boiler were so fitted to the pinnacle that they could be taken out in five minutes, or replaced ready for operations in the same brief space of time.

In May, 1842, experiments were also made with the pinnacle on the Grand Junction Canal, in the presence of Sir F. Head and other leading Directors of the Canal Company, and others. Notwithstanding the unfitness of the pinnacle for canal navigation, the results obtained during these experiments were most satisfactory.

Six tug-boats were afterwards built and fitted with disc engines, and employed on the canal between Wolverhampton and Ellesmere Port, until that canal was sold to be converted into a railway. On one occasion one of these boats drew a train of sixteen canal boats the entire distance of upwards of 70 miles, at a cost of 4*d.* per ton for haulage.

In 1849, a disc engine of the same diameter as that represented in the engravings (viz. 27 inches), constructed under the patent of Mr. G. D. Bishopp, was fixed temporarily in H. M. screw steam vessel the 'Minx,' of 300 tons, fitted with a screw-propeller 4 feet 6 inches diameter, to which a pair of horizontal direct-acting engines had already been applied. The disc engine was so fixed that either engine could be coupled to the propeller shaft. A series of trials were then made, of which the following are the particulars supplied by the Admiralty :

RECIPROCATING ENGINES.		DISC ENGINES.		REMARKS.
Date of Trial.	Speed. Knots.	Date of Trial.	Speed. Knots.	
8th Aug. 1849	4·645	14th Nov. 1849	*3·625	* A mean of two runs only, and under unfavourable circumstances.
8th Aug. 1849	4·08	24th Nov. 1849	4·659	
24th Sept. 1849	4·515	12th Dec. 1849	5·148	

Particulars of the Experiments for ascertaining the quantity of Water used, and the number of Revolutions made by the Reciprocating and the Disc Engines.	Reciprocating engine. Jan. 18th, 1850.	Disc engine. Jan. 22nd, 1850.
Duration of trial	11 hrs. 56 m.	12 hrs. 35 m.
Number of revolutions made	79,555	83,638
Average number of revolutions per minute	111·1	110·7
Mean pressure of steam	39·8 lbs.	39·2 lbs.
Quantity of water used	12,120 lbs.	12,120 lbs.

In the above trials the disc and the reciprocating engines were driven by the same boiler, and it will be seen by the first Table that the speed of the vessel was half a knot per hour faster with the disc engine. By the second Table it appears that with the same quantity of water evaporated by the boiler, and therefore with the same consumption of fuel, the disc engine drove the screw-propeller 4083 revolutions more than was accomplished by the other engines.

The 'Minx' is an iron vessel, constructed by Sir W. Symonds, but was not calculated for speed.

Her length is 131 feet; breadth, 22 feet 1 inch; mean draft (when not rigged but ballasted to trim), 5 feet 2½ inches; area of midship section, 82 square feet; displacement, 203 tons; tonnage, builders' old measurement, 303 tons.

The 'Minx' was originally fitted with engines of 100 H.P., which were replaced by a pair of horizontal high-pressure engines, and without the latter being removed the disc engine was temporarily fixed in her for trial.

The following are the particulars of the trials with the three different engines :

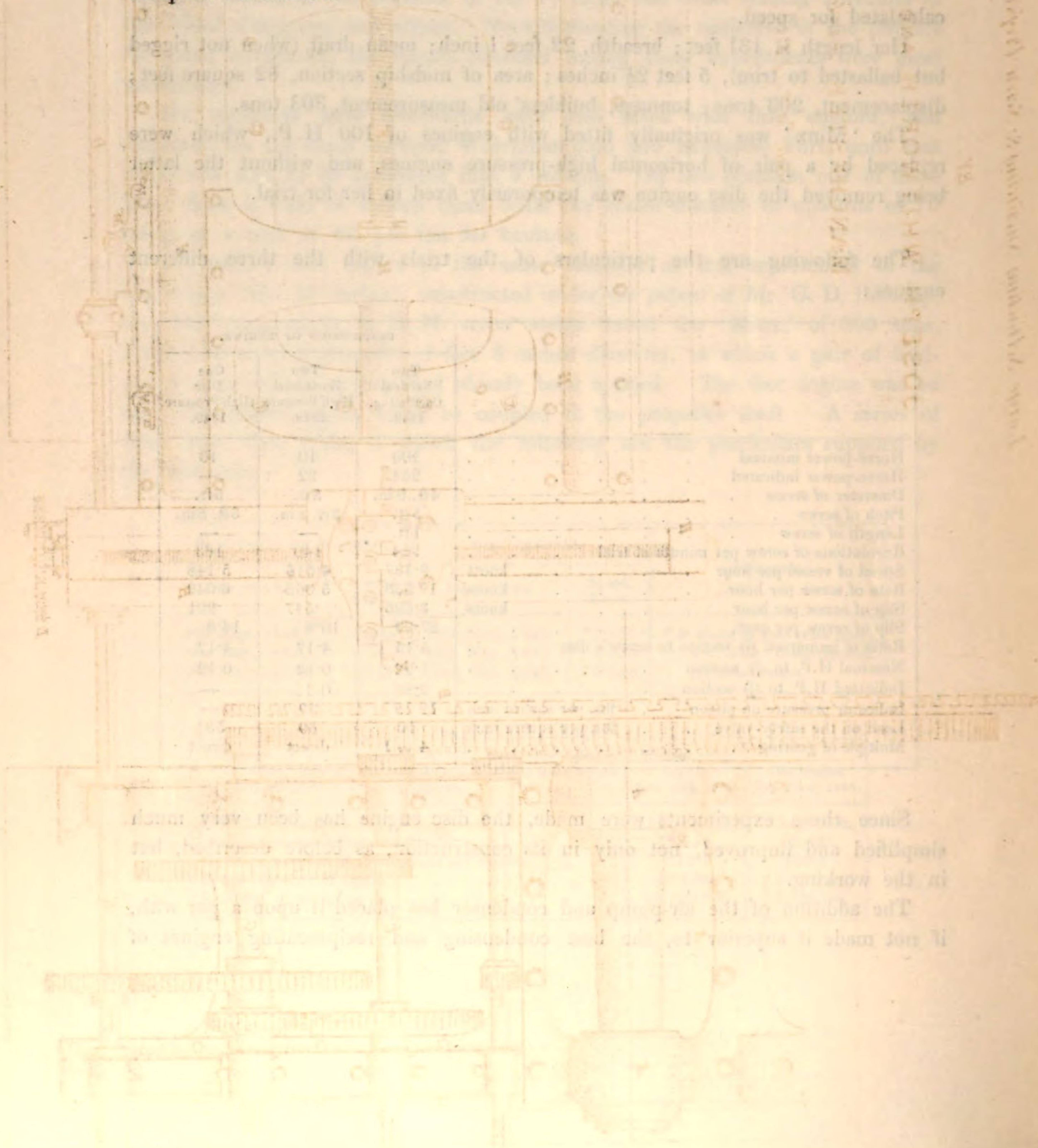
	DESCRIPTION OF ENGINE.		
	Two Vertical Oscillating. 1848.	Two Horizontal High Pressure. 1849.	One Disc High Pressure. 1849.
Horse-power nominal	100	10	10
Horse-power indicated	234	32	—
Diameter of screw	4 ft. 6 in.	5 ft.	5 ft.
Pitch of screw	5 ft.	3 ft. 8 in.	3 ft. 8 in.
Length of screw	1 ft.	—	—
Revolutions of screw per minute at trial	254	140	163
Speed of vessel per hour knots	9.137	4.515	5.148
Rate of screw per hour knots	12.533	5.062	6.049
Slip of screw per hour knots	3.396	.547	.901
Slip of screw per cent.	27.09	10.8	14.8
Ratio of immersed ⊕ section to screw's disc	5.15	4.17	4.17
Nominal H.P. to ⊕ section	1.22	0.12	0.12
Indicated H.P. to ⊕ section	2.86	0.38	—
Indicator pressure on piston . . . lbs. per square inch	12.19	39	—
Load on the safety-valve . . . lbs. per square inch	10	60	53½
Multiple of gearing	4 to 1	direct	direct

Since these experiments were made, the disc engine has been very much simplified and improved, not only in its construction, as before described, but in the working.

The addition of the air-pump and condenser has placed it upon a par with, if not made it superior to, the best condensing and reciprocating engines of

modern times; and the successful working of the engine of 16 horses' power at 'The Times' newspaper office, with its condenser and air-pump, for the last three years, with scarcely any repair, is a complete test of its durability.

The engine at 'The Times,' however, has not received the latest improvements,—but an engine of 20 horses' power, recently made by Messrs. Rennie for Messrs. Marshall and Company's Works at Shrewsbury, has given the most complete satisfaction.



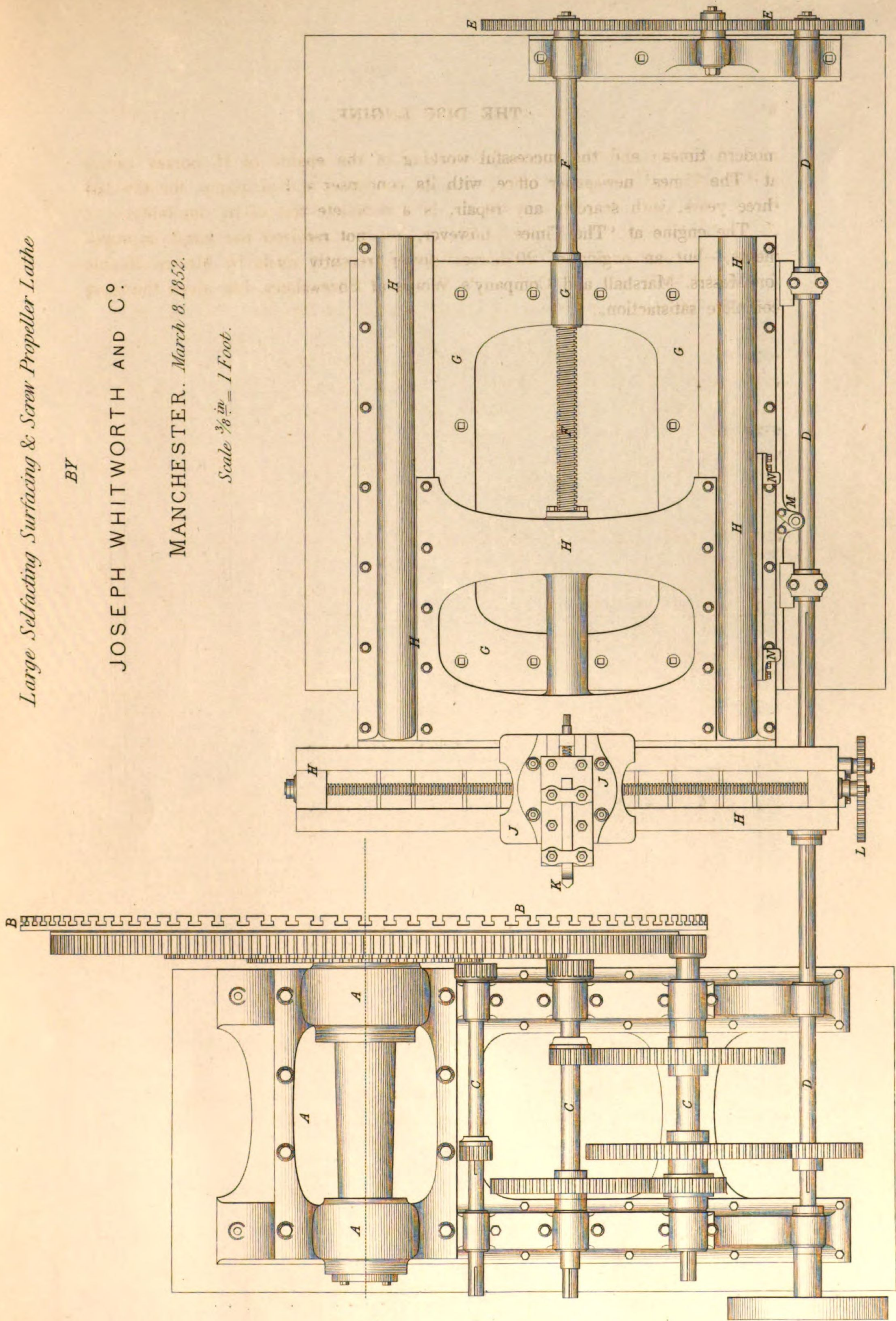
Large Selfacting Surfacing & Screw Propeller Lathe

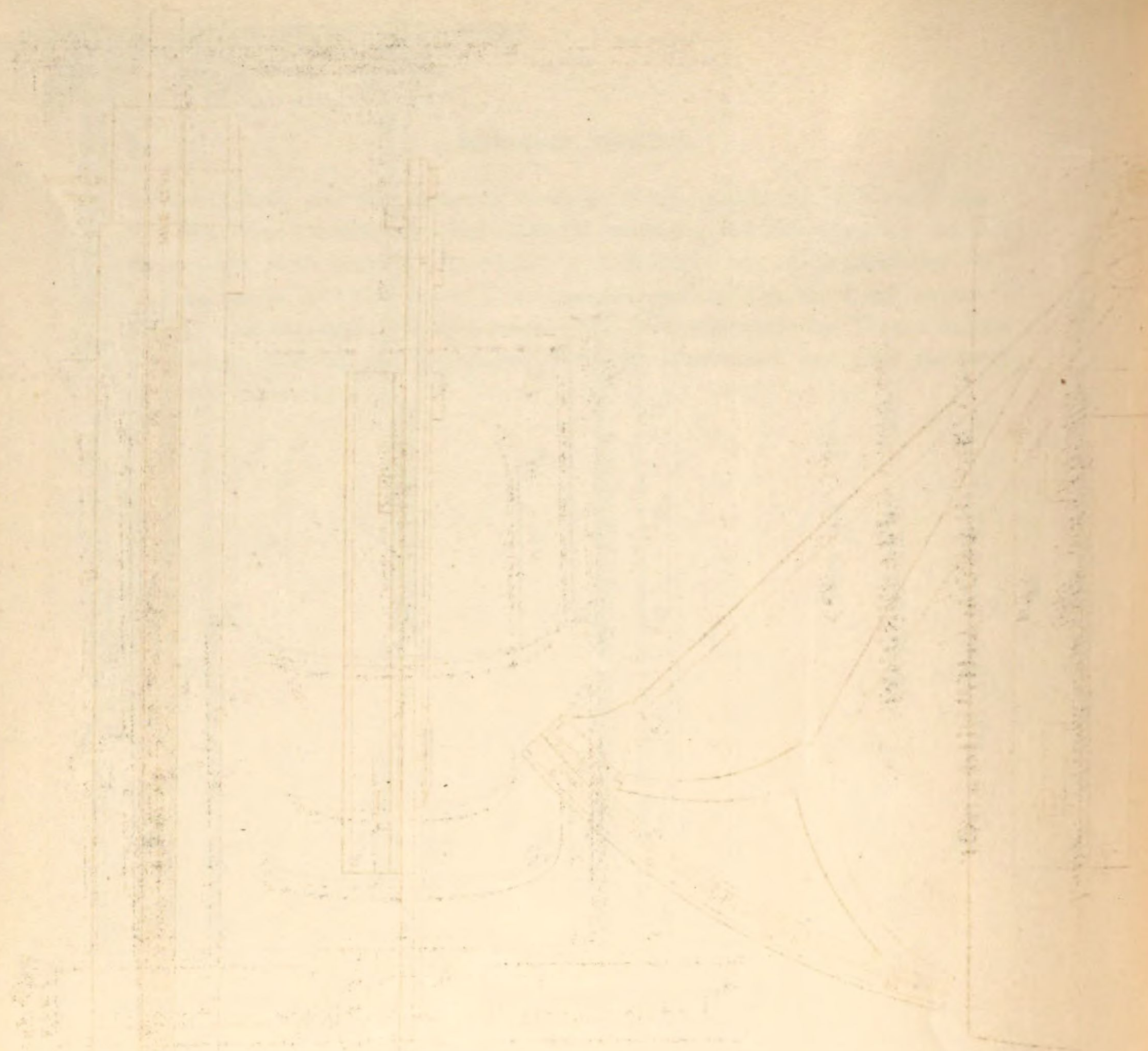
BY

JOSEPH WHITWORTH AND C^o

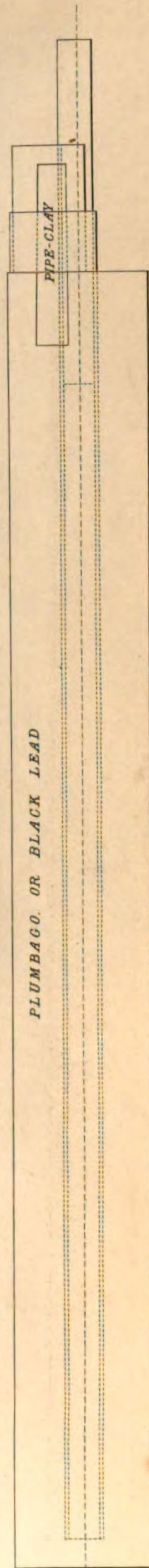
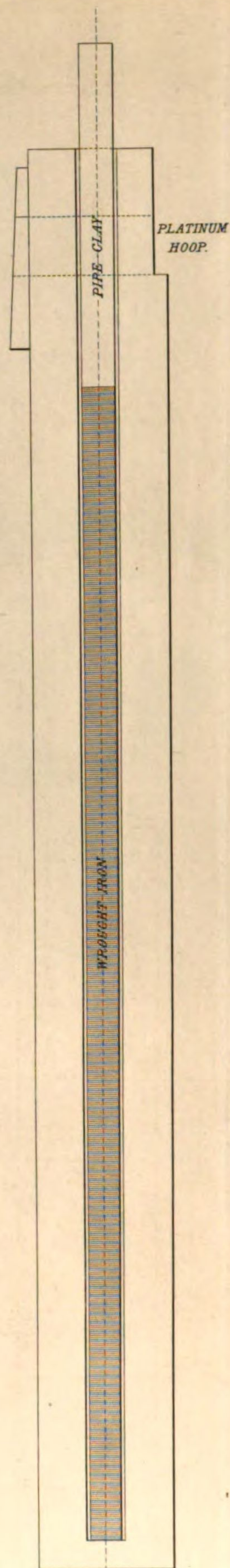
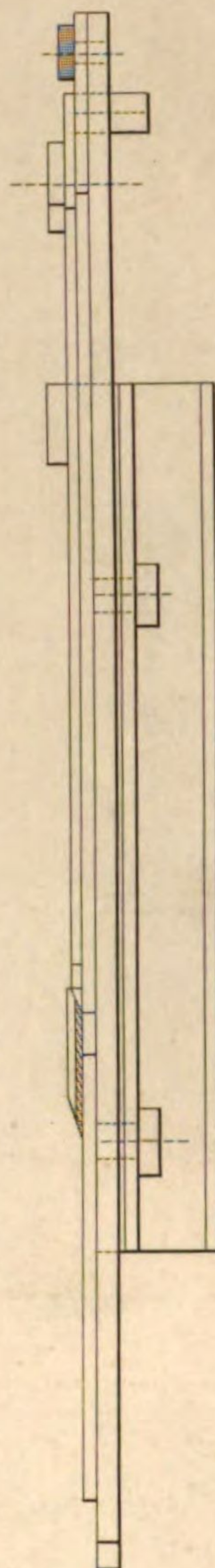
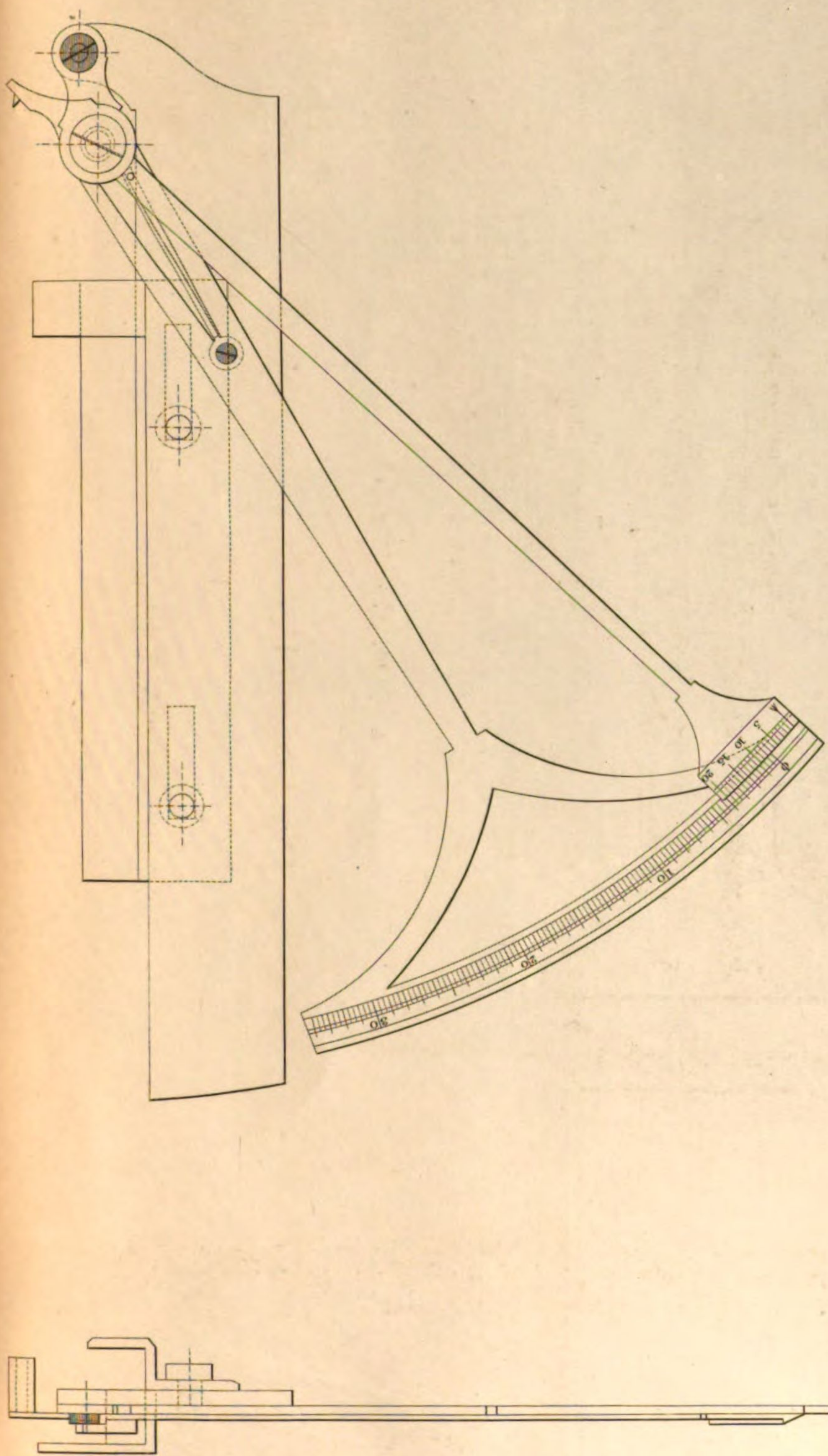
MANCHESTER. March 8. 1852.

Scale $\frac{3}{8} \text{ in} = 1 \text{ Foot.}$



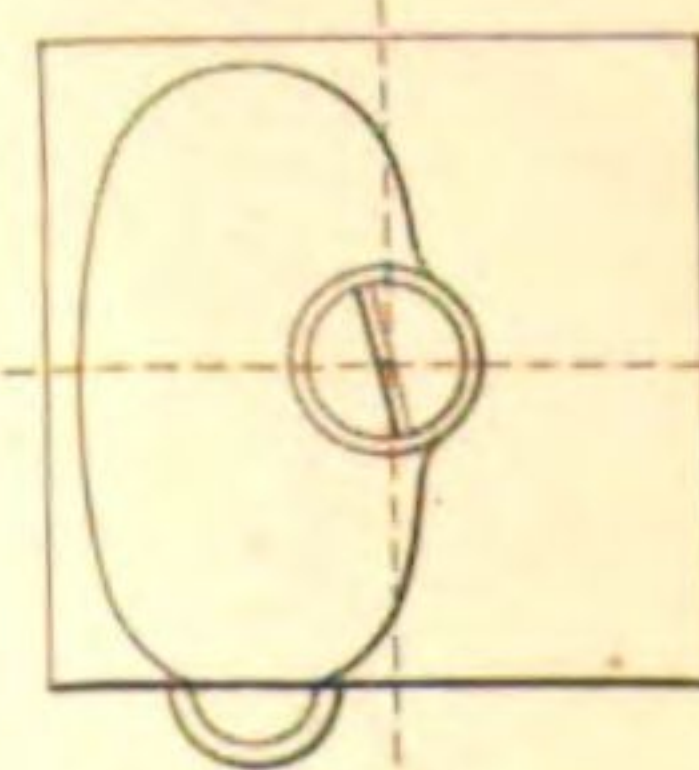


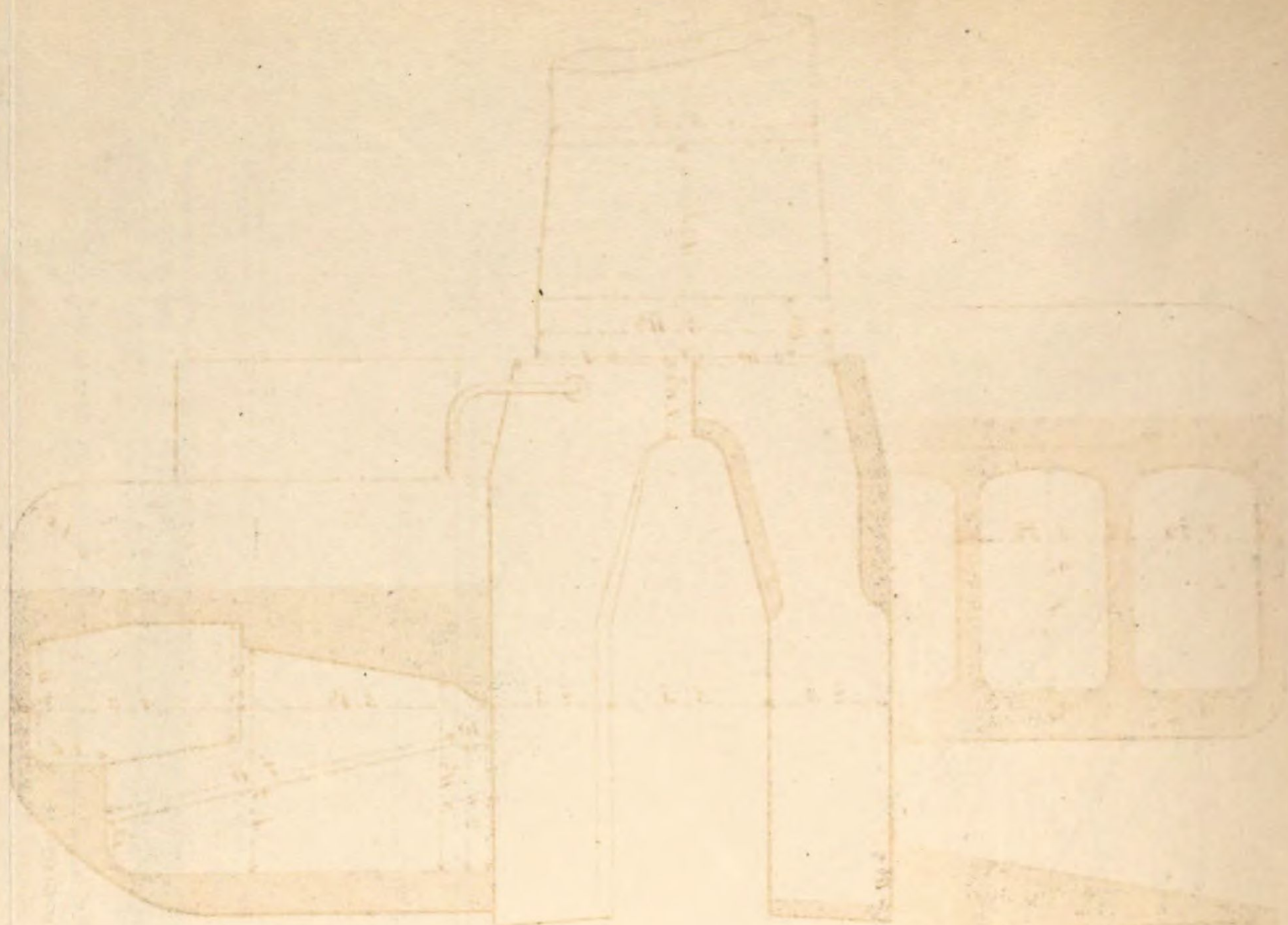
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DANIELL'S PYROMETER.

FULL SIZE.





Tube 1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

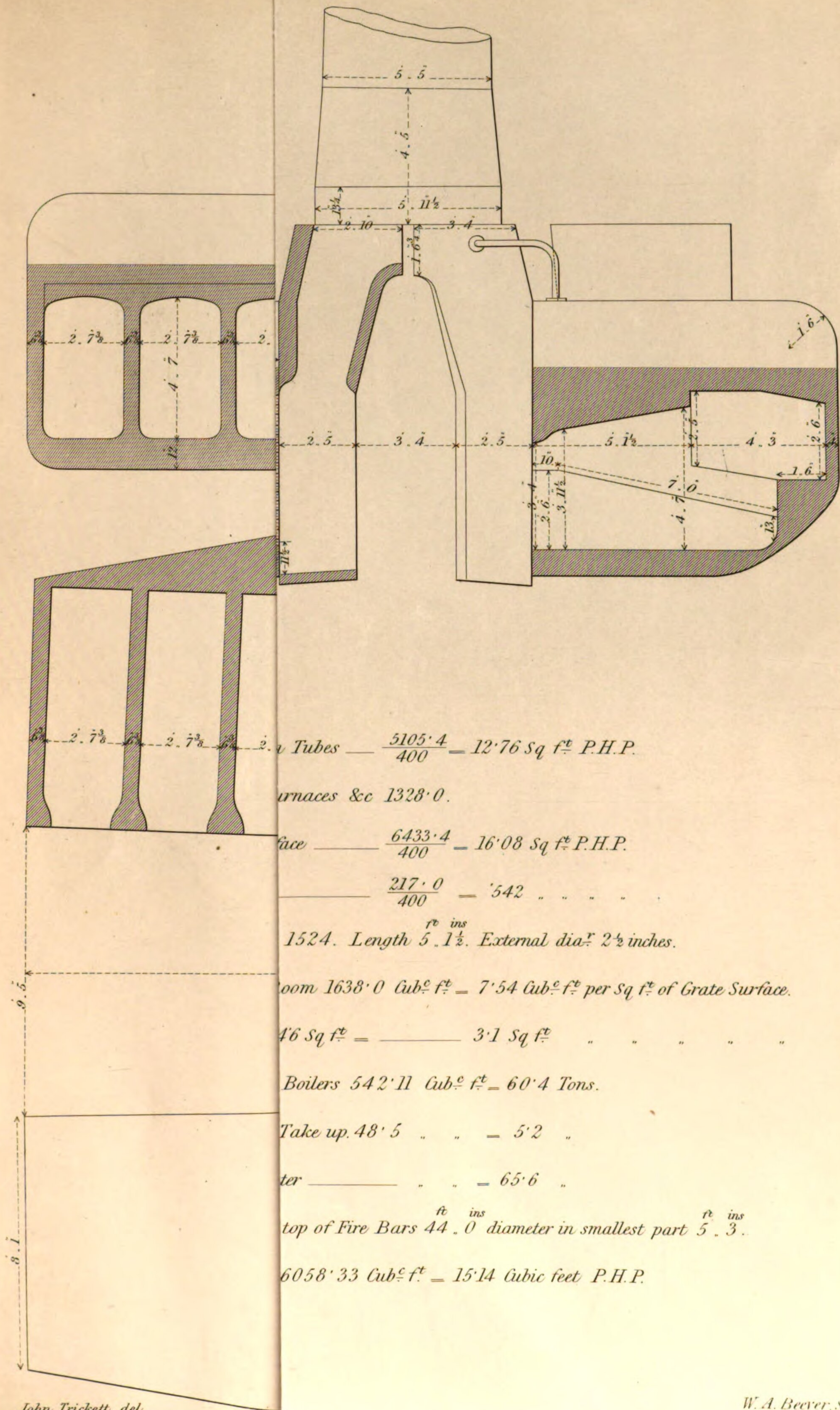
1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

1000 12 1/2 x 1/2

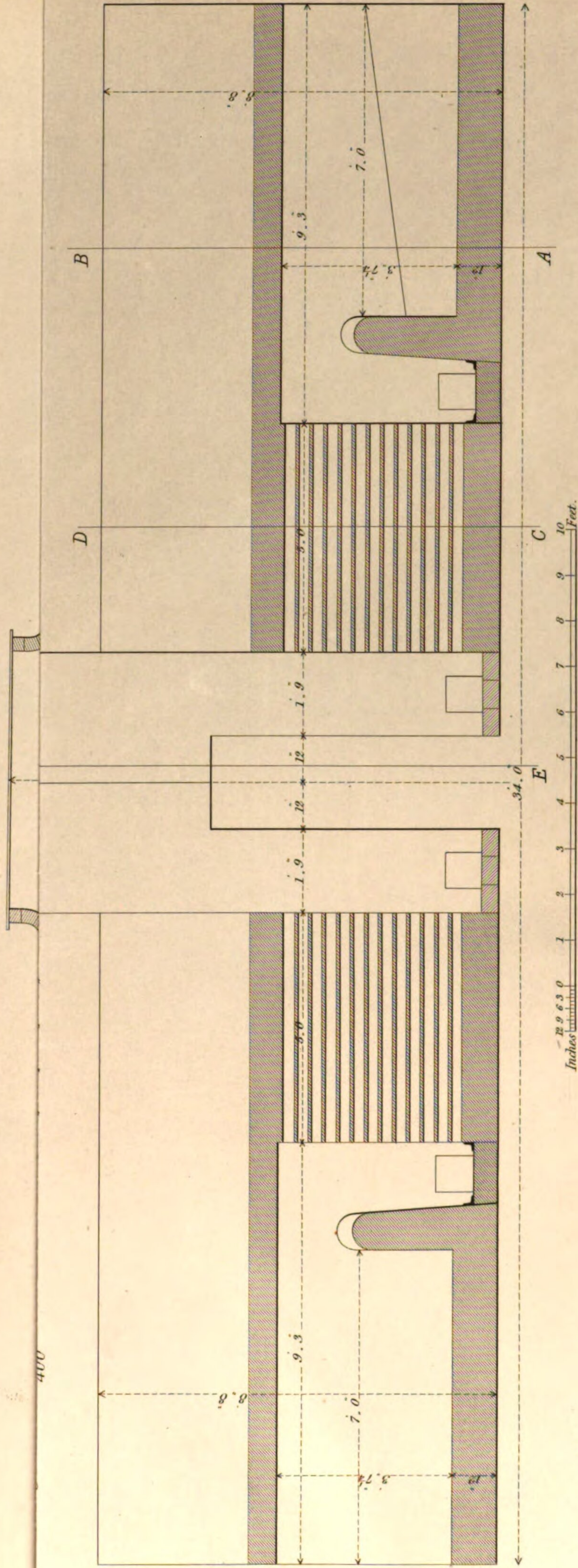
1000 12 1/2 x 1/2



H. M. S.

NIGER 400 H.P.

007

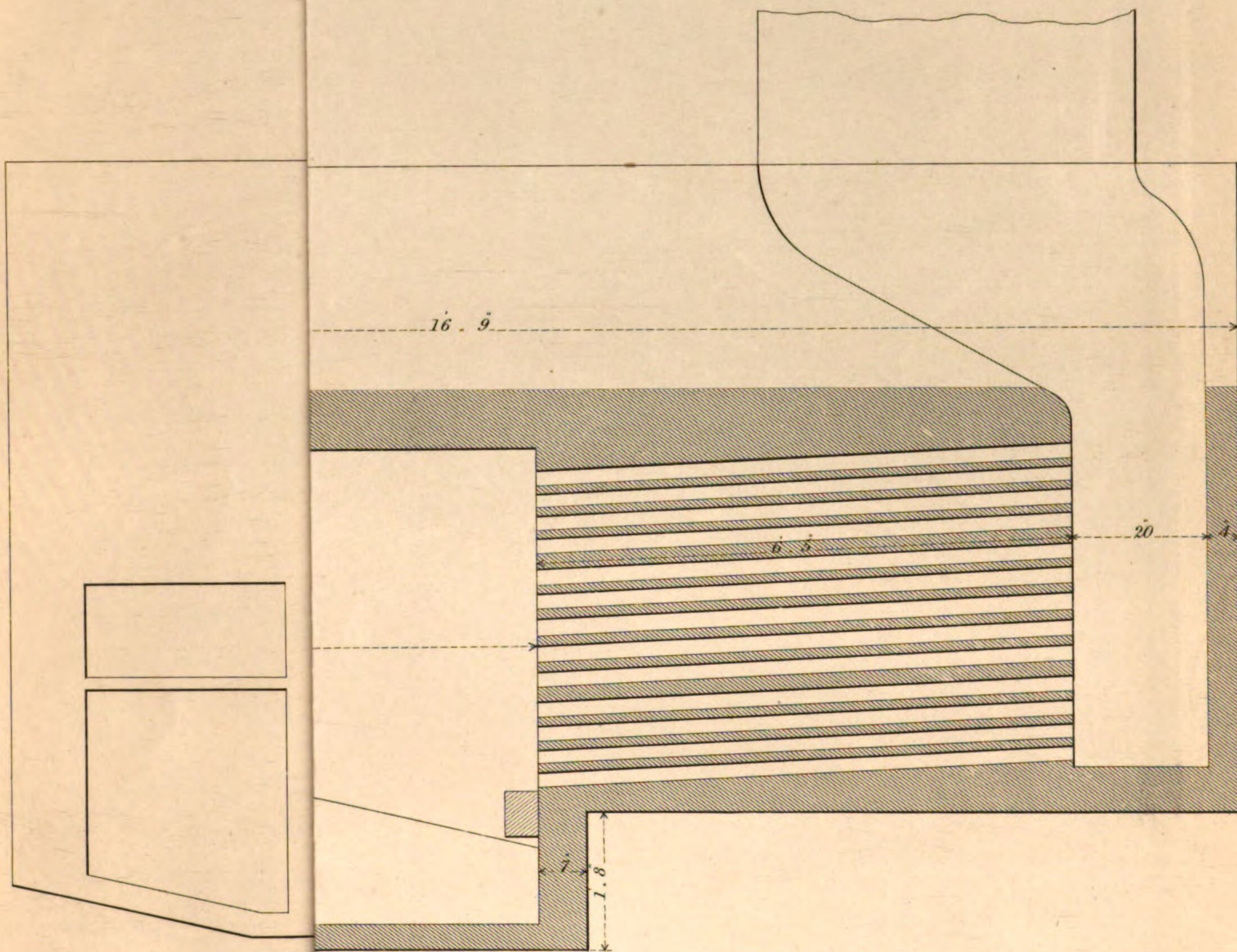


W. A. Beever, Sc.

London, John Weale, 1852.



Machine for the
purpose of the
the light of the
the light of the
the light of the



" Furnaces &c 853'6.

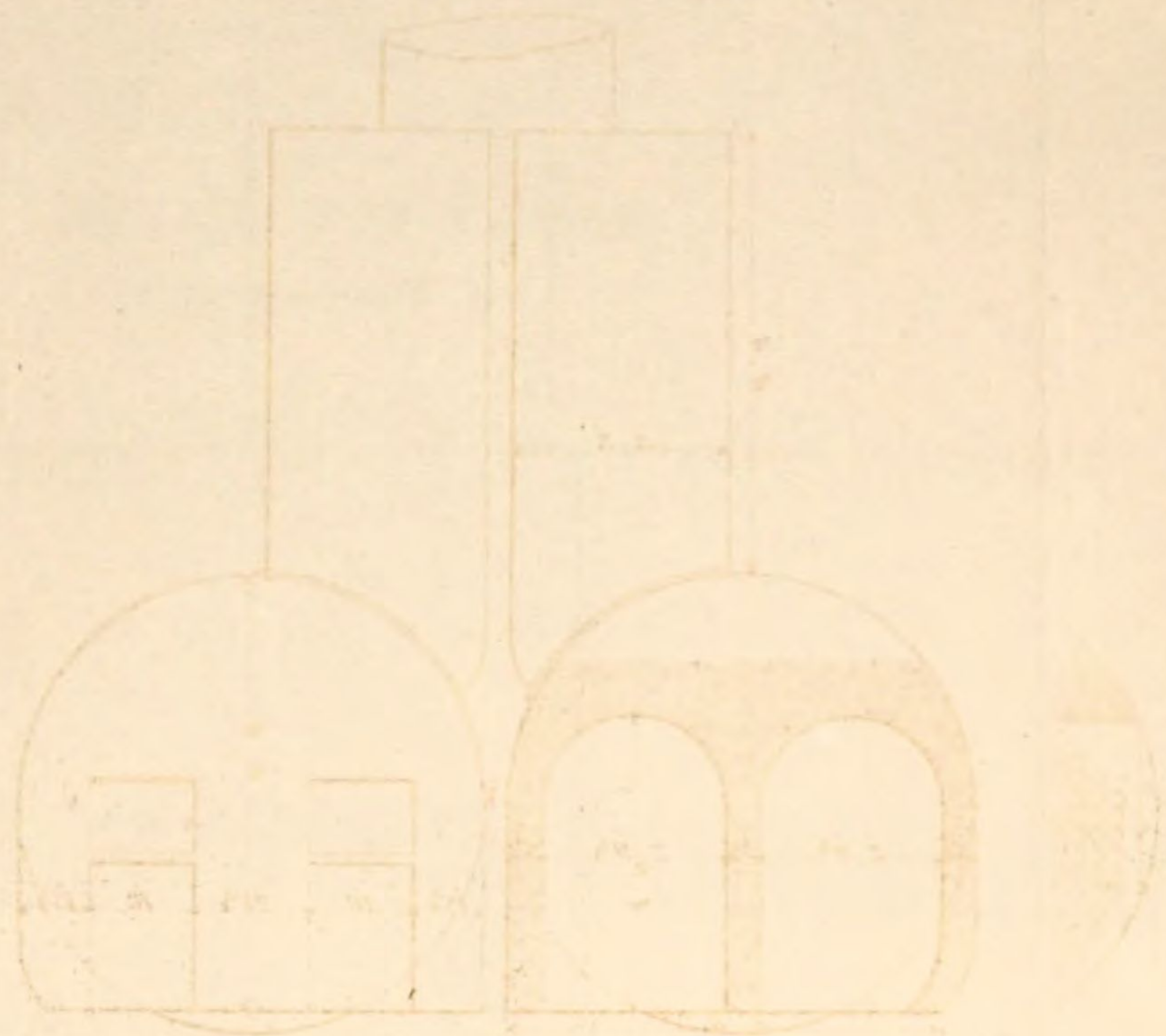
Steam Room Heating Surface $\frac{6024'4}{401}$ 14'9 Sq ft per H.P.

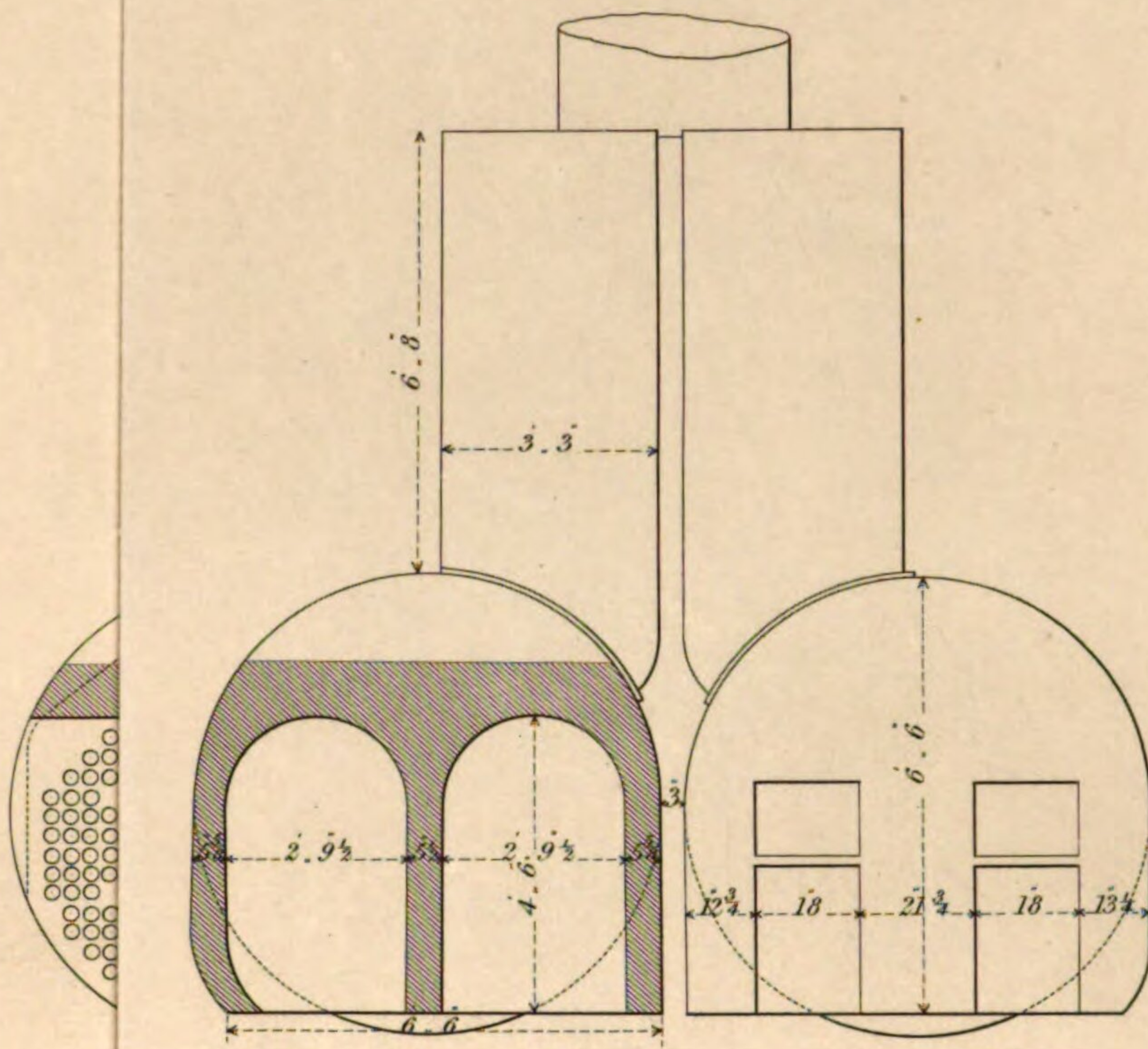
Water Surface Tubes 1240. Length 9' 5. Outside diameter 2½ inches.

Heating Surface Bulk of Boilers 5306' 2661.

John Trickett. del.

W.A. Beever. Sc.





Grate Surface *Content of Steam Room 384'425 Cubic ft = 5'008 " " "*

Heating Surface *Content of Boilers — 2091'514 Cubic ft = 19'013 P.H.P.*

" " *Diam of Cylinder 42 ins. Stroke 3' 0". 2 Cylinders Oscill'g.*

Total Heat *10th Oct. 1849. Tried in the River, with these Boilers.*

N^o of Tubes *Mean Pressure on the Piston by Indicator ^{lbs} 23'142 ft² per Sq inch.*

Area of Water *Revolutions per Minute 38. Indicated H.P. 443'0.*

John Trice

W. A. Beever, Sc.

OF THE PRODUCTION OF VESSELS

ON

THE PADDLE-WHEEL

BY

GEORGE RENNIE ESQ

LONDON

ON
THE PROPULSION OF VESSELS
BY
THE PADDLE-WHEEL.

BY GEORGE RENNIE, ESQ.

F. R. S., &c. &c.

THE PROPULSION OF VESSELS THE PADDLE-WHEEL

vessels by mechanical power has been fully developed in
 recent years—in the first instance by Mr. Trevithick, and
 now and Moray. In the ninth Section, Mr. Trevithick
 is of vessels for stability, speed, capacity, and strength
 upon the kinds of vessels for different purposes—the
 opinion,—the nature of the engines adapted for vessels
 is,—and the species of fuel and its management to obtain
 economy to point out the law which governs the stability
 to the experiments of Besant and others, and give
 as derived from similar authorities.
 others, he traces them from the ancient and simple means
 down to the more complicated system of inclined planes
 water. He shows that the action of propellers is
 with paddle-wheels and screw-propellers, or otherwise.
 He states that when the same are compared, the
 ton multiplied by the resistance must be equal to the
 vessel's resistance when reduced to the same direction. It
 which act at intervals only must require to be of greater
 it continuously; hence, unless there be some other
 circumstance alone must determine it in respect of weight
 in which the paddle is the better.

the Editors.
 but in the 2nd volume of the *Encyclopædia Britannica* (1874) the
 the *Collection of Papers* (London, 1874) is a valuable source of
 information.

ON THE PADDLE-WHEEL.

THE subject of propelling vessels by mechanical power has been fully developed in the early editions of the present work, — in the first instance by Mr. Tredgold, and subsequently by Messrs. Barlow and Mornay. In the ninth Section¹ Mr. Tredgold has based it upon the forms of vessels for stability, speed, capacity, and strength: “it depends,” he says, “upon the kinds of vessels for different purposes,—the resistance and modes of propulsion, —the nature of the engines adapted for vessels, —the strength of their parts,—and the species of fuel and its management to obtain the best effect.” He endeavours to point out the law which governs the stability of floating bodies according to the experiments of Bossut and others, and gives formulæ for their resistance as derived from similar authorities.²

On the subject of propellers, he traces them from the ancient and simple modes of oars and paddle-wheels down to the more complicated system of inclined planes, curved surfaces, and jets of water. He shows that the actions of propellers may either be continuous, as with paddle-wheels and screw-propellers, or alternative, as with oars and jets of water. He states that when the actions are continuous, the area of the surfaces in action multiplied by the resistances must be equal to the area of the vessel by the vessel's resistance when reduced to the same direction. It is obvious that all those which act at intervals only must require to be of greater area than those which act continuously: “hence, unless there be some other manifest advantage, this circumstance alone must determine us to reject all except the first or continuous class,” in which he includes the screw.

¹ See page 309, vol. ii. ‘Marine Engines.’

² See Professor Moseley's Paper in the 2nd volume of the Philosophical Transactions for 1850,—‘On the Dynamical Stability and on the Oscillation of Floating Bodies, according to experiments made by Mr. Rawson in Portsmouth Dockyard.’

ON THE EFFECT OF PADDLE-WHEELS.¹

The effect of paddle-wheels is determined by Mr. Tredgold by means of formulæ which represent the velocity of the exterior and interior portions of the floats,—the resistance of one square foot of float-board,—the differential of the effective power and the direct power of the floats, which must be equal to the resistance of the vessel,—or, in other words, of the area and velocity of the centre of pressure of the floats, whereby the power to produce the effect must be equal to the resistance of the vessel. This pressure must in all cases be proportional to the square of the velocity, minus the velocity of the vessel through the water. This law is, however, subject to modifications dependent upon the velocity of the floats and the difference between their plus and minus pressures. The rules given by Mr. Tredgold are not sanctioned by his editor, as they are inadequate to embrace the different cases presented by the action of paddle-wheels in propelling vessels, and for which he substitutes four new equations, by means of which the whole theory is embodied. These equations show, that with given sized paddle-wheels and with given draughts of water, the velocities under all circumstances will be proportional to the cube root of the quantity of steam consumed per minute: a second equation shows that more steam may be consumed by either increasing the length of the stroke or by diminishing the radius of the wheel; while the latter equations indicate a corresponding increase of the velocities in the ratio of the cube root of the increased consumption.

As regards the oblique action, it is shown that the loss does not exceed a fortieth part of the whole, and may be safely neglected, as the mean direction of the action is of greater importance to the motion than the loss of power. He then gives equations for different kinds of floats, such as those of a rectangular, triangular, and parabolic form, showing at the same time that there is an obvious advantage in the latter, as an equal resistance is obtained with a less breadth of float, while the resistance is least when it strikes and leaves the water, and greatest when in a vertical position; and in proposing the parabolic form, Mr. Tredgold derived his idea from its approximation to the fins of a fish, and which are used for impelling in the same manner, so that while the rectangular float strikes the water with its whole breadth, the parabolic float strikes it sooner, and gradually acquires its full hold of the water. The best position for the float is a plane passing through the axis, in order that the resistance or plus pressure may be the greatest possible.

The advantages derivable from large wheels are represented to consist in their more direct action,—that they enter and quit the water more freely, and disturb it less.

And finally, as regards the modifications which have been applied to paddle-wheels for the purpose of getting rid of certain defects, Mr. Tredgold considers that

¹ See page 322, vol. ii. 'Marine Engines.'

the remedies have generally been worse. He thinks, however, that if a certain degree of elasticity were given to the arms of paddle-wheels, and the floats were made parabolic, they would be a great improvement.

MR. BARLOW'S EXPERIMENTS.

The subject of paddle-wheels was afterwards considered in a very valuable communication made to the Royal Society, and published in the 'Philosophical Transactions,' in 1834, entitled 'On the Motion of Steam Vessels,' by P. W. Barlow, Esq. Impressed with its importance, and of the advantages which might be derived from an inquiry on the subject, Mr. Barlow availed himself of the opportunity presented by his residing in the neighbourhood of Woolwich Dockyard, where many steam vessels were constantly lying. By the aid of the Government, he instituted a series of experiments upon the speed and performance of several of the best steam vessels in the Service; and the results having been frequently verified, they were tabulated so as to show the relative tonnage, horse-power, consumption of fuel, diameter of the wheels, dimensions of the floats, their velocity through the water, the relative velocity of the vessel and the pressure upon the floats, the comparative effect between the common wheel and the cycloidal or Morgan's wheel,¹ and the ratio of the speed of a steam vessel to the power employed to propel it. These were illustrated by the actual performances of vessels employed in the Post-Office Service between Liverpool and Kingstown, and by those of vessels on long voyages.

The most important, however, are contained in Table I., namely, on the comparative resistance of a steam vessel to that of a plane surface.² The comparative resistances between plane and curved surfaces exposed to the shock of a fluid and moving through it had already been investigated by many philosophers, from the period when Sir Isaac Newton made his experiments on the resistances of a pendulum oscillating in a fluid, down to the more elaborate and extensive experiments of Beaufoy: but we are not aware that any one had, previously to Mr. Barlow, compared the resistances of vessels on a large scale; and the very important conclusions which have been derived from these experiments have enabled us to calculate the elements of resistance in a steam vessel more correctly than heretofore.

"It is evident," says Mr. Barlow, "that when the power of a steam engine is employed in propelling vessels through the medium of a fluid by the reaction of a paddle-wheel, there results an unavoidable loss of a large portion of the power of the engine,—first, by the action of the paddle being oblique or at an angle with the horizontal direction of the vessel in every position except the vertical one, by which a portion only of the power exerted on the paddle becomes effective; and secondly, by the receding of the wheel in the water necessary to create a resistance equal to the force applied by the engine. This source of lost power must

¹ Originally invented by Elijah Galloway.

² See Table I., page 8.

exist in all paddle-wheels, whatever their construction, from the resistance being created in a fluid; but the radial paddle being subject to these defects, many contrivances have been proposed to remedy the evil, by causing the floats to keep a vertical position by the aid of machinery during their progress through the water." This remedy has been applied very extensively in the paddle-wheel invented by Galloway, usually termed Morgan's. Similar modifications had been applied by Seaward and Maudslay. As before stated, with the aid of these experiments Mr. Barlow had been enabled to determine and calculate in each case the relative velocity of the wheel and vessel, the actual pressure upon the vertical paddle, the area of paddle per horse-power, and other facts; and by comparing these data with the velocity, tonnage, &c., a just conception may be formed, not only of the action of each paddle-wheel and the manner in which the power of the engine is expended, but also the amount of surface, proportion of the paddles, dip of immersion, &c., which are required to produce the greatest useful effect. Mr. Barlow then gives formulæ for finding the centre of pressure of a paddle-wheel, by which it becomes easy to calculate the degree of resistance to the paddles at any angle of inclination, and the whole power of the engine, either by obtaining the sum of all the resistances of one paddle passing through the water, and multiplying by the number, or by finding the mean resistance of one paddle in action by the centre of pressure.

The general results of the second Table¹ show that the power expended on the common radial wheel, as compared with the vertical paddle in Morgan's, is in the ratio of .546, .151, and .197; that is, in Morgan's wheel *the vertical position is the most effective in propelling the vessel, and in the common wheels the least so*, contrary to the received opinion, the best effect being produced in Morgan's wheel between the angles of 60° and $65^\circ 33'$; thus showing in the former case the great quantity of power absorbed by the oblique action of the common wheel, whereas in the vertical wheel the ratio of the whole effect will be that of the velocities of the wheel and vessel in the ratio of 3.2, or .660 of the whole power. This is illustrated by the experiment contained in the third Table,² wherein it is shown that when the vertically-acting wheel is slightly immersed, little or no advantage is gained, as the additional velocity required to obtain the necessary resistance is fully equal to the loss by the oblique action of the floats in the common radial wheel; but when the immersion is deep, the loss in the common wheel absorbs .447 of the power, while the loss from Morgan's wheel remains nearly the same. This applies particularly in rough weather, when the loss of the former is great as compared with the latter. As respects another description of paddle-wheel on the cycloidal principle of Field and Galloway, the results contrast favourably with Morgan's in small immersions, and show a greater equality of effect in different im-

¹ See Table II., page 9.

² See Table III., page 10.—For further elucidations see also De Mornay's deductions.

mersions, as compared with other wheels. As regards the relation between the diameter of the wheel, the area of the paddle, and the velocity of the vessel, Mr. Barlow shows that when the area of the float of a paddle-wheel is so adjusted to any given diameter, the engine is capable of performing its whole duty, and that this same duty might be performed with a less paddle, a larger wheel, or *vice versa*, but that the velocity of the vessel would be the same in both cases. To determine this question he gives two equations, from which he deduces, first,—that the two velocities are to each other inversely as the square root of the radii; and secondly,—that the new area of paddle will be found to increase and decrease so rapidly that little practical advantage can be taken of the condition of the first equation.

It appears, however, that there are two ways,—one by reducing the paddle, and the other by reducing the diameter of the wheel,—by which, in the former case, the speed of the vessel will remain the same, and by the latter it will be increased as the cube root of the power developed in both cases.

As regards the first Table of experiments, on the comparative resistance of a steam vessel to that of a plane surface, it is shown, that contrary to the results of all experiments hitherto made on a small scale, the resistance of a well-shaped vessel does not exceed $\frac{1}{17}$ th part of a plane of the same sectional area.¹

The method adopted in arriving at these results is by taking the effective pressure in pounds exerted by the engine, the velocity of the vessel, the velocity of the vertical paddles through the water, the area of the paddle-board, the area of the vertical paddles, and the immersed sectional area of the vessel,—so that by comparing the power required to urge the plane or midship section through the water with the actual power employed by the engine to move the vessel at the same velocity, the difference shows the mere resistance or mobility of the vessel, which difference is shown to vary in different vessels from $\frac{1}{15}$ th to $\frac{1}{24}$ th of the force or power necessary to urge the plane of equal section through the water. These valuable experiments were found to coincide very nearly with those of Colonel Beaufoy, who showed that the force necessary to urge a plane through the water of one square foot area, at the rate of eight nautical miles per hour, was 203·79 lbs. Taking, therefore, the experiments on the 'Medea,' which moved with the velocity of 11·33 miles per hour, or 966 feet per minute, it would require, according to Colonel Beaufoy, (the resistance being as the square of the velocity,) 308 lbs., which being applied to the area of the midship section of the vessel, multiplied into its velocity, and the product divided by the usual allowance per horse-power, would give the power necessary to urge the plane forward at that rate.

¹ "In the following Table is given the effective pressure exerted by the engines in every experiment where the dip or immersion of the paddle is given; but the comparison of the resistance of the vessel to a plane is of course limited to those experiments only in which the area of the immersed section could be ascertained.

TABLE I.

Name of the vessel.	Tonnage.	Horse power.	Effective pressure exerted by the engine.	Velocity of the vessel, that of the wheel being 1.	Velocity of the vertical paddles through the water, that of the wheel being 1.	Area of the paddle board.	Area of a vertical paddle equal in effect to all the paddles.	Immersed sectional area of the vessel.	Ratio of the resistance of the vessel to that of a plane surface of the same section.
			lbs.			feet. in.			
Medea	835	220	4536	·627	·373	19 0	54·00	263	$\frac{1}{15}$
Flamer	494	120	2814	·683	·317	16 0	52·44	174	$\frac{1}{15}$
Flamer	494	120	2593	·674	·326	16 0	57·60	218	$\frac{1}{16}$
Firebrand	494	120	2472	·667	·333	12 9	38·56	200	$\frac{1}{16}$
Firebrand	494	120	2527	·666	·334	12 9	42·00	214	$\frac{1}{16}$
Columbia	360	100	1807	·654	·346	12 0	43·10	202	$\frac{1}{18}$
Salamander	820	220	2150	·833	·167	22 6	398·70	359	$\frac{1}{17}$
Dee	710	200	2531	·732	·268	20 0	69·00	209	$\frac{1}{19}$
Firefly	550	140	3808	·733	·267	18 0	201·00	275	$\frac{1}{11}$
Firebrand	494	140	2474	·772	·228	18 0	128·61	200	$\frac{1}{17}$
Pluto	365	100	985	·823	·117	16 6	105·23	116	$\frac{1}{24}$
Monarch	872	200	7167	·748	·252	20 0			
Monarch	872	200	6976	·746	·254	20 0			
Monarch	872	200	7002	·756	·244	20 0			
Magnet	360	140	3672	·763	·237	15 0			
Meteor	296	100	4320	·671	·229	13 6			
Carron	294	100	1731	·777	·323	13 6			
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.

"It thus appears, contrary to the results of all experiments hitherto made on the small scale, that the resistance of a well-shaped vessel does not exceed $\frac{1}{17}$ th part that of a plane of the same sectional area.

"The above mean, being founded on several experiments, must be very near the truth; although in each so much error may exist, from the want of minute attention to the number of strokes of the engine, as to afford no test of the best shaped vessel.

"As, however, the results are very extraordinary, it may be well to submit them to a totally independent mode of estimation. In the above investigation, the mean number of acting paddles, with their corresponding velocities and areas, are compared with the sectional area of the vessel and its velocity; but we might have made the calculation in another way,—that is, by comparing the force necessary to urge a plane section equal to that of the vessel with the velocity at which it passes through the water, with the actual power of the engine employed to propel the vessel,—which ought to give nearly the same fraction as the other method.

"Of the whole power of the engine, we have seen that with the vertically-acting paddle one-third is lost by the retrograding of the wheel: in the 'Medea,' therefore, the power employed in propelling the vessel is two-thirds of 220 = 146 horse-power: now the velocity of the vessel having been 11·33 English miles per hour, or 16·62 feet per second, the resistance in feet of water is $\frac{(16·62)^2}{64\frac{1}{3}}$, and in lbs. $\frac{(16·62)^2}{64\frac{1}{3}} \times 62\frac{1}{2}$, on each square foot. The number of feet in the section is 263, and the velocity in feet per minute is 997; the whole force, therefore, expended in a minute, is 70,796,970, which, divided by 33,000, gives 2150 horse-power for the force necessary to urge a plane section of 263 feet through the water at the rate of 11·33 miles per hour: but the vessel itself is urged with that velocity by the power of 146 horses; the resistance to a vessel is therefore to that of a plane section of the same area as 146 to 2150, or as 1 to 15 very nearly, which exactly agrees with the number given in the Table. The agreement is equally close in the 'Flamer;' and the mean obtained this way from the whole set of experiments is very nearly the same as that given in the above Table.

TABLE II.—EXPERIMENTS ON PADDLE-WHEELS.

Exhibiting the Ratio of the Velocity of the Wheel and Vessel, the whole Pressure upon the Vertical Paddle, and other results calculated from the preceding experiments.

	Name of the vessel.	Tonnage.	Horse power.	Quantity of coals in chaldrons.	Diameter of the wheel.	Length of the paddle board.	Depth of the paddle board.	Number of paddles.	Dip of the extremity of the paddles.	Strokes of the engine per minute.	Number of strokes per minute for full power.	Speed of the vessel in English miles.	Area of paddle per horse power.	Tons burden per horse power.	Velocity of the vessel, that of the wheel being 1.	Diameter of rolling circle.	Diameter to centre of pressure.	Pressure upon the vertical paddle in lbs.	Proportion of the power of the engine expended on the vertical paddles.
1.	Messenger . . .	730	200	60	19 4	10 0	2 0	16	ft. in.	20½	22	9.75	.200	3.65	.754	feet. 13.31	feet. 17.65	838	.154
2.	Messenger . . .	730	200	130	19 4	10 0	2 0	16	—	18	22	8.00	.200	3.65	.706	12.45	17.63	926	.171
3.	Dee . . .	710	200	30	19 4	10 0	2 0	16	1 6	23	22	10.61	.200	3.55	.717	12.91	18.00	1089	.195
4.	Rhadamanthus	820	220	46	20 4	9 0	2 6	16	—	20	22	10.39	.204	3.73	.791	14.54	18.36	695	.121
5.	Salamander . .	820	220	210	20 4	9 0	2 6	16	6	15	22	8.15	.204	3.73	.828	15.21	18.36	257	.045
6.	Phoenix . . .	820	220	12	20 4	9 0	2 6	16	6	21	22	11.7	.204	3.73	.829	15.60	18.57	464	.082
7.	Monarch . . .	872	200	—	21 0	10 0	2 0	18	6	20½	22	10.72	.200	4.36	.757	14.62	19.31	976	.197
8.	Monarch . . .	872	200	—	21 0	10 0	2 0	18	6	20½	22	10.50	.200	4.36	.756	14.60	19.31	952	.193
9.	Monarch . . .	872	200	—	21 0	10 0	2 0	18	3 6	21	22	11.02	.200	4.36	.760	14.69	19.31	998	.200
10.	Alban . . .	294	100	14	13 0	9 0	1 6	14	9	27	30	8.84	.270	2.94	.777	9.15	11.77	354	.119
11.	Pluto . . .	365	100	14	14 4	9 0	1 10	14	—	26½	30	10.15	.330	3.65	.823	10.71	13.01	308	.114
12.	Hermes . . .	730	140	130	17 6	9 0	2 0	—	1 6	18	24	6.3	.257	5.21	.645	9.80	15.86	1138	.294
13.	Meteor . . .	296	100	8	13 0	9 0	1 6	—	6	32	30	9.0	.270	2.96	.671	7.87	11.70	1083	.362
14.	Firebrand . . .	494	140	10	17 0	9 0	2 0	14	4	24	24	10.15	.257	3.53	.772	11.88	15.38	691	.174
15.	Firefly . . .	550	140	152	17 6	9 0	2 0	14	4	20	24	8.3	.257	3.93	.733	11.60	15.81	673	.173
16.	Magnet . . .	360	140	6	16 0	10 0	1 6	—	8	29½	24	11.75	.214	2.57	.756	11.16	14.72	882	.213
17.	Carion . . .	294	100	8	13 0	9 0	1 6	—	4	28	30	9.15	.270	2.94	.777	9.15	11.77	385	.129
18.	Medea . . .	835	220	20	21 0*	4 10†	3 11	11	3 11	22½	22	11.33	.172	3.79	.627	13.79	22.03	3024	.666
19.	Flamer . . .	494	120	15	13 0	5 9	2 9	9	3 11½	27	27½	10.9	.266	4.11	.683	11.30	16.55	1715	.625
20.	Flamer . . .	494	120	112	13 0	5 9	2 9	9	5 6	24	27½	9.57	.266	4.11	.674	11.16	16.55	1441	.526
21.	Firebrand . . .	494	120	12	14 6	4 6½	2 10	9	2 11½	28	27½	10.55	.212	4.11	.667	10.50	15.73	1508	.476
22.	Firebrand . . .	494	120	40	14 6	4 6½	2 10	9	3 7	27	27½	10.10	.212	4.11	.666	10.48	15.73	1404	.454
23.	Columbia . . .	360	100	80	14 0	3 11	3 0	9	4 10	24	30	8.5	.237	3.60	.654	9.91	15.15	1008	.546

* Polygon. † Mean length.

TABLE III.

Angle at which the centre of pressure of the paddle entered the water.	Proportion immersed of the radius of the wheel.	Effective power, that of the engine being 1.		Lost power, that of the engine being 1.		Mean effective resistance, the resistance of the vertical paddle being 1.		Mean resistance opposed to the engine, that of the vertical paddle being 1.		Remarks.
		Common wheel.	Morgan's wheel.	Common wheel.	Morgan's wheel.	Common wheel.	Morgan's wheel.	Common wheel.	Morgan's wheel.	
35°	·252	·660	·666	·340	·333	1·298	·702	1·457	·674	Vessel very light, the immersion to the top of the paddle. Mean immersion of experiments.
44	·350	·645	·666	·355	·333	1·510	·547	1·750	·522	
50	·430	·620	·666	·380	·333	1·628	·504	1·971	·482	
60	·550	·553	·666	·447	·333	1·850	·425	2·510	·404	{ Very deep immersion.

"From an examination of the above Table, we arrive at several important conclusions. In the first place it is seen that when the wheel is slightly immersed, little or no advantage is gained from the vertically-acting paddle, the loss from the additional velocity required to obtain the necessary resistance or receding of the wheel being fully equal to that of oblique action in the common wheel. The only remedy for such an evil is the increase of the number and dimensions of the paddles, both of which are difficult to accomplish in Morgan's wheel: we may therefore very fairly conclude, that in the navigation of rivers or smooth water, where generally little variation is required in the degree of immersion of the vessel, the common wheel, if properly proportioned, is preferable to the vertically-acting wheel, in consequence of its admitting of a larger surface of paddle-board.

"In the case of deep immersion the effect is very different: here the loss from oblique action in the common wheel becomes very serious, so that the total loss of the engine amounts to ·447 of that expended, while the loss from Morgan's wheel remains nearly the same. It therefore appears, that the latter has great advantages over the common wheel for sea purposes or long voyages, where the immersion of the vessel is constantly diminishing by the exhaustion of the coals and other stores required at the commencement of the voyage. The loss from the oblique action of the paddles must also be very great in rough weather, from the degree of immersion to which the wheel is subject; in addition to which, the paddles entering the water with so great a velocity, receive a reaction or blow which has the effect of nearly bringing up the engine, and there in consequence results a loss, in addition to that of oblique action, from the power required to put the mass of machinery again in motion."—*P. W. Barlow.*

Mr. A. De Mornay states that the subject of paddle-wheels has been very amply treated by the above author. After noticing the various modifications of paddle-wheels by Buchanan, Bernhard, Symington, Oldham, and others, the author investigates the theory of the two classes of paddle-wheels, one with fixed, the other with feathering floats.

If the paddle-wheels of a steam vessel be made to revolve, the vessel being at rest, as is always the case at first starting, any given part comprised within the floats of one of the wheels (if of the first class) will describe a circle; but as

soon as the vessel has acquired a certain velocity, its path will be lengthened out into a curve, which is called a 'curtate' cycloid.

This curve continues to lengthen as the vessel gains velocity, and becomes the common cycloid when the velocity of the vessel is equal to the circumferential velocity of the given point. If the speed of the vessel go on increasing, the given point will describe a curve called a 'prolate' cycloid. By circumferential velocity is understood the velocity of any point of the wheel relative to the centre of the shaft, or, in other words, what its absolute velocity would be, if the centre being stationary, the wheel made the same number of revolutions in the same time.

It is evident that when the vessel has attained her maximum speed, there will be a series of points in each wheel situated at a distance from its axis, and which will describe common cycloids. Diagrams are given in Plates I. to VIII., showing the positions of the arms and floats as they successively come into action: the fulcrum is obtained by means of the reaction of the water on the paddle-board; the resistance to be overcome is that of the water to the motion of the vessel, acting at the centre of the wheel, and in the direction of the vessel's course; and the power is that of the engine applied at the extremity of the crank: then, since the fulcrum is obtained by means of the reaction of the water on the float, it follows that the true fulcrum is situated at that point on which, if immersed, there will be no reaction.

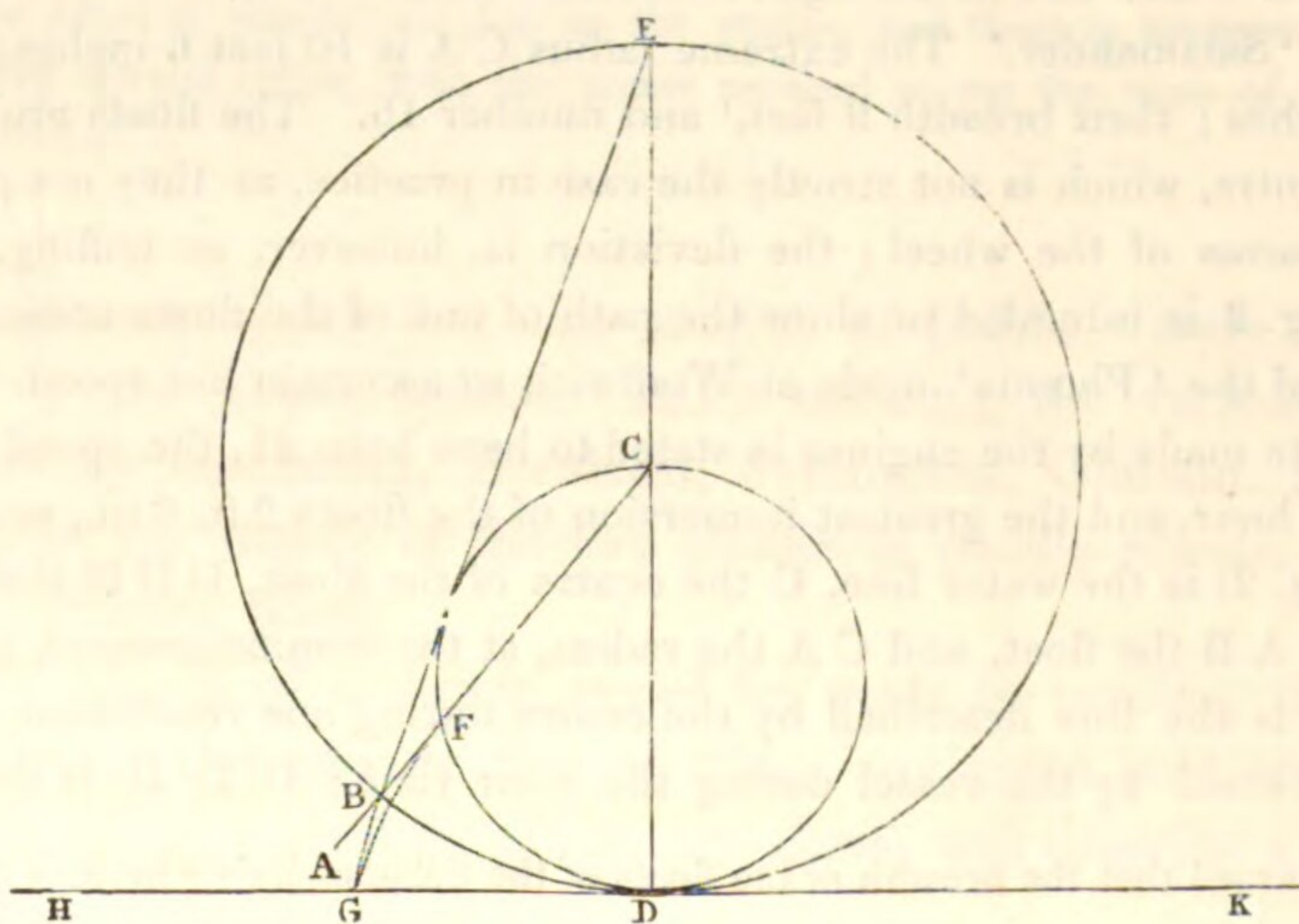
We will now quote Mr. De Mornay's opinions on the subject.

To illustrate the motion of paddle-wheels, we will refer to Plate I. where Fig. 1 is a diagram of the common wheel as fitted to Her Majesty's steam vessels 'Phoenix,' and 'Salamander.' C is the centre of the shaft; r, r, r , represent the arms; and A B, A B, A B, the floats. L L is the water line at the light immersion of the 'Phoenix,' and L' L' at the deep immersion of the 'Salamander.' The extreme radius C A is 10 feet 6 inches; the depth of the floats 2 feet 6 inches; their breadth 9 feet,¹ and number 16. The floats are here drawn radiating from the centre, which is not strictly the case in practice, as they are generally fixed on one side of the arms of the wheel; the deviation is, however, so trifling, that it is of no importance. Fig. 2 is intended to show the path of one of the floats according to the result of the mile trial of the 'Phoenix' made at Woolwich to ascertain her speed. The number of strokes per minute made by the engines is stated to have been 21, the speed of the vessel 11.7 statute miles per hour, and the greatest immersion of the floats 2 ft. 6 in., or exactly their own depth. L L (Fig. 2) is the water line, C the centre of the shaft, D D D the circumference of the *rolling circle*, A B the float, and C A the radius, at the commencement of a revolution of the wheel; C C' is the line described by the centre during one revolution, which is equal to the distance traversed by the vessel during the same time; D' D' D' is the position of the

¹ We have since learned that the breadth of the floats of the Salamander's wheels is only 8 ft. 9 in.—M.

rolling circle, and $A^{11} B^{11}$ that of the float at the end of the revolution. The *curtate cycloid* $A A^1 A^{11}$ is the line described by the outer edge of the float, and $B B^1 B^{11}$ that described by its inner edge; and the various positions of the float are shown at intervals of one-sixteenth of a revolution. In order to render the motion of the float through the water more distinct, the node has been drawn on an enlarged scale in Fig. 3, where $Aa^1 A^{11}$ is a part of the curve described by the outer edge of the float, and $Bb^1 B^{11}$ a part of that described by its inner edge, $L L$ the water line, $a b$ the position of the float at the instant of entering the water, $a^1 b^1$ its position soon after the immersion of the lower edge, being the end of one of the intervals mentioned above, $a^1 b^1$ at the end of the next interval, $a^1 b^1$ in the middle of the stroke, and so on, $a^{11} b^{11}$ being its position at the instant of leaving the water. Figs. 4 and 5 relate to the performance of the 'Salamander' at the mile trial, when the greatest immersion of the floats is stated to have been 5 feet 6 inches, the number of revolutions 15, and the speed 8.15 statute miles per hour.

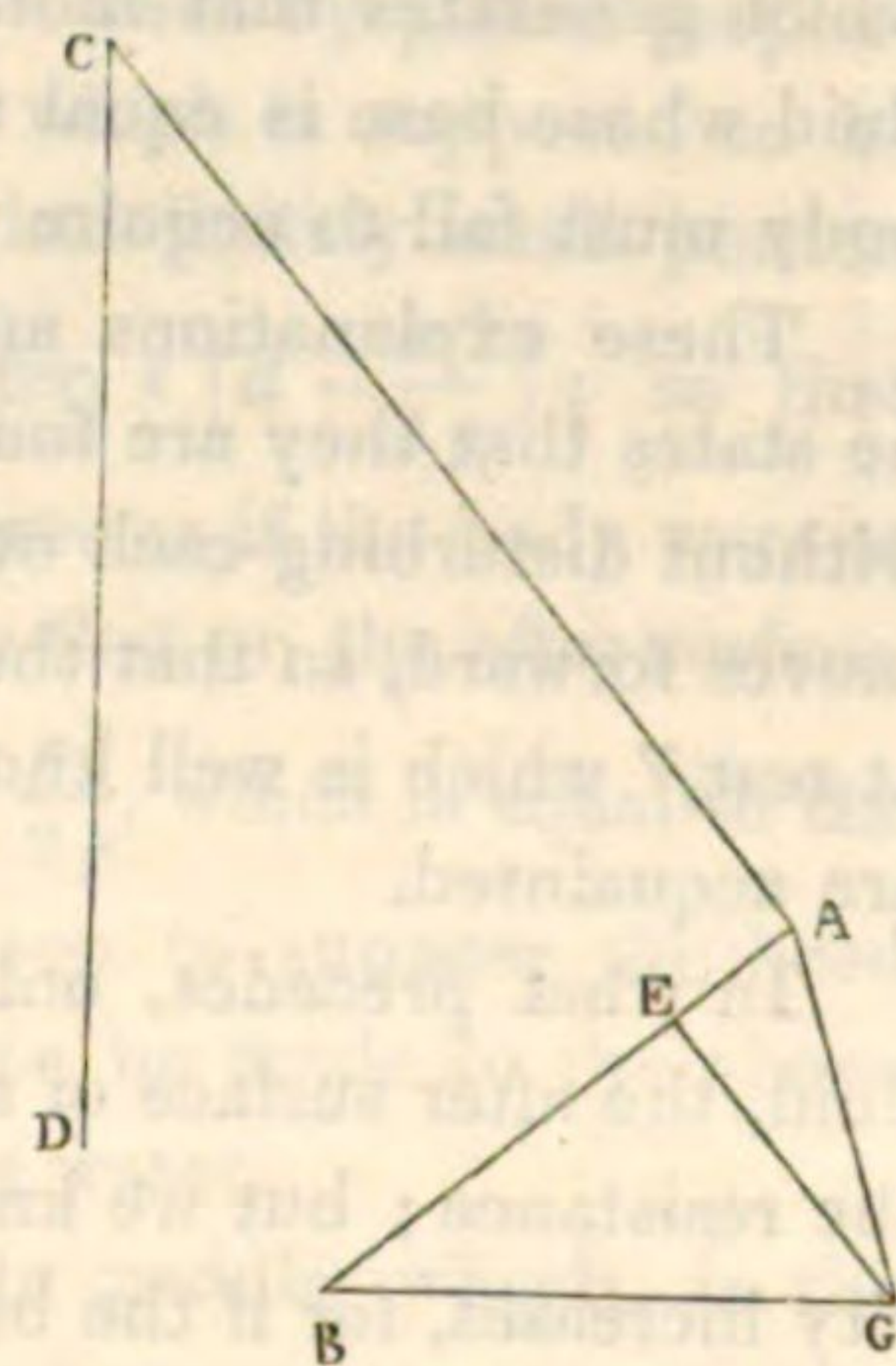
It has already been observed, that every point of a common paddle-wheel situated on the circumference of the *rolling circle* describes a common cycloid: let $C A$ in the annexed diagram represent a radius of the wheel, intersecting the circumference of the *rolling circle* at the point B , and let $D E$ be the vertical diameter of the *rolling circle*. On $C D$ as a diameter describe a circle intersecting the radius $C A$ at the point F . The arc $F D$ of this circle is equal to the arc $B D$ of the *rolling circle*, being the measure of twice the angle measured by the latter in a circle of half the radius; therefore if the two circles $E B D$, $C F D$, roll simultaneously along the horizontal straight line $H K$, so as to preserve the same relative positions, the points B and F will coincide at some point G on that line, and will describe two cycloidal arcs, to the latter of which the radius $C A$, or its production on the opposite side of the centre, will always be tangent at its intersection F with the circumference $C F D$; this point is, therefore, in any given position of the radius moving in the direction of the radius itself, which consequently has no angular velocity at this point. The whole radius may thus be conceived to move in its own direction, and at the same time to revolve about the point F . If we call ρ the radius of the *rolling circle*, and ϕ the angle $A C D$ contained between the given radius and the vertical, the distance $C F$ is equal to $\rho \cos. \phi$.



ON THE ACTION OF PADDLE-WHEELS.

Every paddle-wheel may be regarded as a series of levers, coming successively into action. Each lever is represented by one of the arms of the wheels, at the extremity of which a float is attached: the fulcrum is obtained by means of the reaction of the water on the paddle-board; the resistance to be overcome is that of the water to the motion of the vessel acting at the centre of the wheel and in the direction of the vessel's course; and the power is that of the engine, applied at the extremity of the crank, which thus forms a bent lever with each arm of the wheel. Now, since the fulcrum is obtained, as above stated, by means of the reaction of the water on the float, and there can be no reaction unless the surface of the float move through the water, it follows that the true fulcrum is situated at that point on which, if immersed, there would be no reaction. This is the point F found above; for, as it moves in the direction of the surface of the float, it can meet with no resistance from the water. A certain expenditure of power is therefore necessary to force the floats through the water, in addition to that required to propel the vessel.

It is evident that the mean horizontal pressure on the floats of a steam vessel must be equal to the resistance opposed to the motion of the vessel; therefore the motive power must be equal to the mean product of the total pressure on the floats by their velocity perpendicular to their surface, plus the product of the mean horizontal pressure by the velocity of the vessel. This sum in the common wheel is equal to the mean product of the total pressure on the floats by their *circumferential velocity*; for let CA in the annexed figure represent a radius of the wheel, CD a vertical line, and A a point of the surface of the float; also let AB, perpendicular to CA, represent the *circumferential velocity* of the given point, and the horizontal line BG the velocity of the vessel. Join AG, and draw GE parallel to CA. The motion of the given point is in the direction of the line AG, the length of which represents its velocity. Let p be the pressure on the point A in the direction BA, perpendicular to the surface of the float; the pressure in the direction GA will be $p \sin. AGE$, and the power required to overcome that resistance at the velocity AG will be $p \sin. AGE \times AG = p \times AE$. The horizontal pressure is equal to $p \cos. ABG = p \times \frac{BE}{BG}$, which, multiplied into the velocity of the vessel, gives $p \times BE$ for the propelling effect. The sum of these two quantities is $p [AE + BE] = p \times AB$, which is the product of the total pressure on the given point by its *circumferential velocity*, as was to be proved.



This is true only for wheels with radiating floats: in all other cases the *velocity* perpendicular to the surface of the float which the given point would have if the axis of the wheel were stationary, must be substituted for the *circumferential velocity*, and, as in the common wheel the motion of each float is perpendicular to its surface when the axis is at rest, these two velocities are identical.

In order to be able to calculate the absolute amount of power required to produce a given effect, it is necessary to be acquainted with the laws which govern the resistance of fluids to the motion of solid bodies in them, which are generally admitted to be based on the following

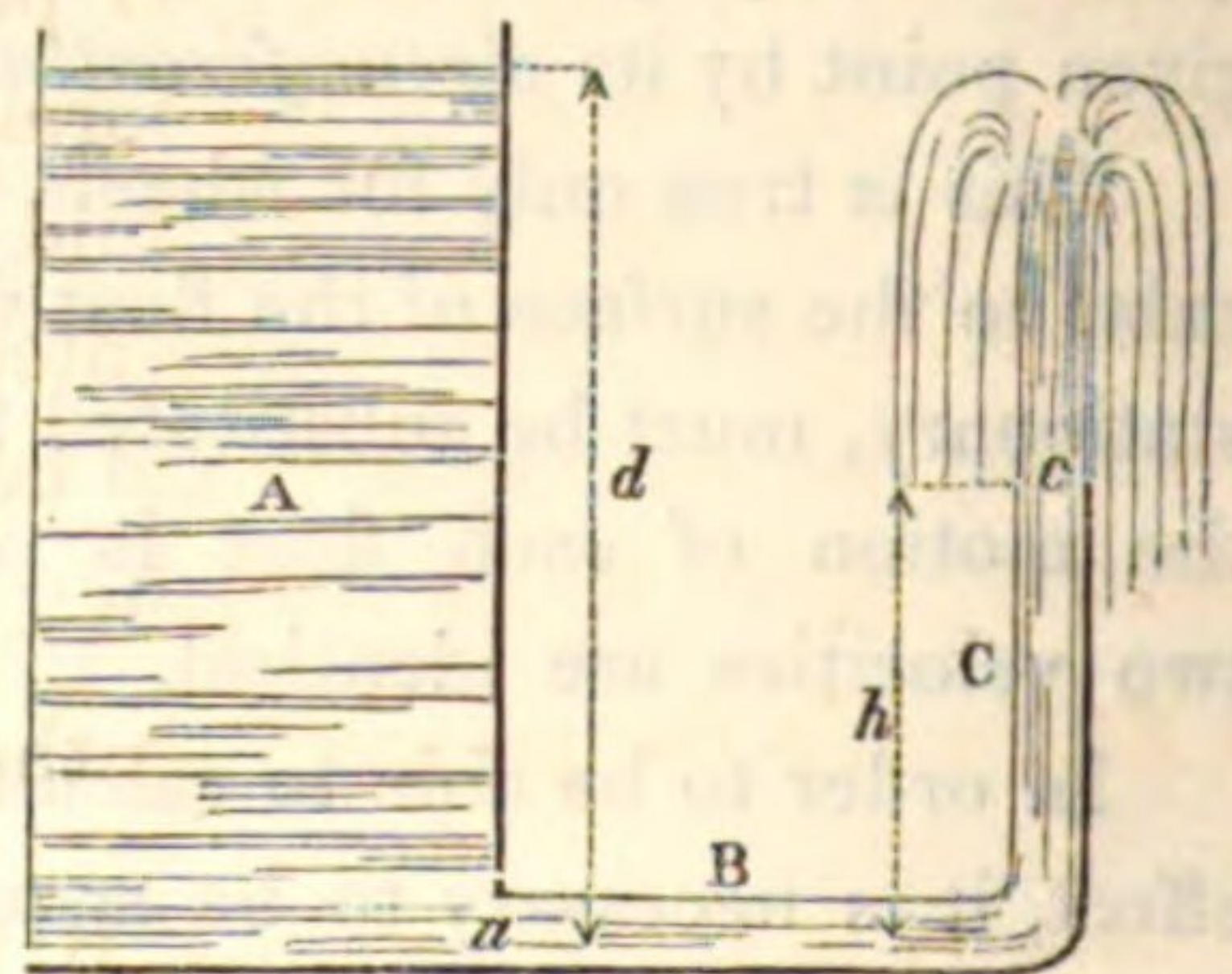
theorem. — Prop. 1. If a plane surface move at a given velocity through a fluid at rest in a direction perpendicular to itself, the resistance is proportional to the density of the fluid and to the square of the velocity of the plane, or it is equal to the weight of a column of the fluid whose base is equal to the area of the surface, and altitude equal to the height through which a body must fall by the force of gravity to acquire the given velocity; which, if v denote the velocity of the surface in feet per second, a its area in square feet, and w the weight of a cubic foot of the fluid, is equal to $a \frac{v^2}{2g}$, the altitude due to the velocity v being $\frac{v^2}{2g}$.

It is assumed that the resistance to a plane moving in a fluid at rest is equal to the pressure of the fluid on the plane at rest, the fluid moving at the same velocity and in the contrary direction to that of the plane in the former case; on which hypothesis the ratio of the square of the velocity is explained in two very different ways. The first is, that "the resistance must vary as the number of particles which strike the plane in a given time, multiplied into the force of each against the plane; but both the number and the force are as the velocity, and consequently the resistance is as the square of the velocity." The second explanation is, "that the force of the fluid in motion must be equal to the weight or pressure which generates that motion, which, it is known, is equal to the weight of a column of the fluid whose base is equal to the area of the surface, and altitude the height through which a body must fall to acquire the given velocity."

These explanations are extracted from Dr. Gregory's 'Treatise on Mechanics,' in which he states that they are founded on the hypothesis that "the particles of the fluid move freely without disturbing each other's motions, and that it flows in behind as fast as a plane body moves forward, so that the pressure on every part of the body is the same as if the body were at rest," which is well known to be incompatible with the nature of any fluid with which we are acquainted.

In what precedes, only one plane has been mentioned, namely, that which strikes the fluid, the after surface of a body being supposed, by the hypothesis, to have no influence on the resistance; but we know that the pressure on the after surface must decrease as the velocity increases, for if the body were suddenly abstracted, so as to leave a void, the water which had been pressing on the after surface could only move to fill it with the velocity due to its depth below the surface of the fluid; so that, if the body moved forward with a greater velocity, the fluid would cease to be in contact with it, and could not therefore exert any pressure upon it, much less the same as if the body were at rest. We have not yet met with any explanation of the law according to which this pressure decreases, but we suggest the following.

Let A be a reservoir of fluid, which we will suppose to be water, but the reasoning will apply as well to any other fluid, and let B C be a bent tube communicating with the reservoir by means of the aperture a , at a depth d below the level of the water in the reservoir, which is supposed to be maintained constant, the part B being horizontal, and the part C vertical and open at the extremity c , which is situated at a height h above the level of the aperture a . It is evident that, neglecting the effect of friction, the water will issue from the orifice c with the velocity due to the head $d - h$; or, calling v the velocity of



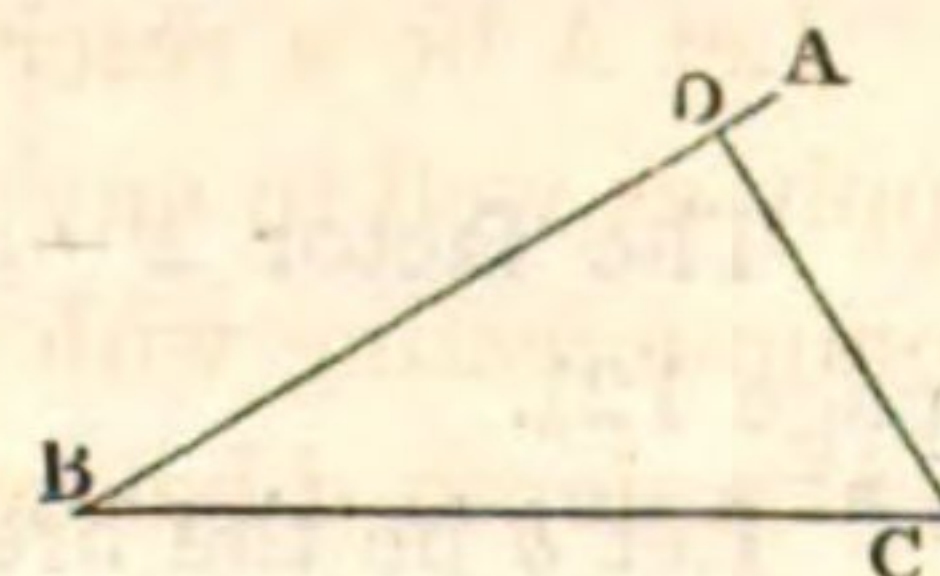
the water, $v = \sqrt{2g(d-h)}$; and if the sectional area of the tube B be equal to the area of the orifice c , the water in it will have the same velocity; so that, if a solid piston were fitted into the tube B, and made to move forward towards the branch C with the above velocity, the pressure on both sides of the piston would be equal, or if the branch C were removed, the pressure of the water in the reservoir on the after service of the piston would be equal to the weight of a column of water whose altitude is equal to h or $d - \frac{v^2}{2g}$. Or it may be explained otherwise, thus: Let a solid body, terminated by a plane at its stern end, move through water in a direction perpendicular to that plane with a given velocity v . The water in immediate contact with the surface must evidently have the same velocity if it remains in contact with it; to generate which velocity in the water a pressure is required equal to the weight of a column whose altitude is $\frac{v^2}{2g}$: this pressure cannot produce any effect on the surface, its force being already expended in producing the motion of the water, and must therefore be deducted from the weight of the total column of water pressing upon the surface when at rest.

Applying this to the case of a prismatic body terminated at both ends by planes perpendicular to its axis, moving through water in the direction of its axis, which is supposed to be horizontal, with a certain velocity v , we find for the pressure on an indefinitely small portion ϵ of its after surface, situated at a depth d below the level of the water, $\epsilon [d - \frac{v^2}{2g}]$; so that if we suppose the pressure on the head end of the body to be the same as if the body were at rest, *i. e.* ϵd on an element of the front surface equal and opposite to that on the after surface, the excess of pressure on the former will be $\epsilon [d - (d - \frac{v^2}{2g})]$ or $\epsilon \frac{v^2}{2g}$, which is equal to the whole resistance as generally assumed. There seems to be no reason to suppose the head pressure to increase with the velocity; so that the only addition to be made to the above resistance would be that produced by the cohesion of the particles of water.

Another theorem, founded on the preceding, and applicable to paddle-wheels, is the following:

Prop. 2. If a plane surface move with a given velocity through a fluid in a direction not perpendicular to itself, the resistance is equal to the weight of a column of the fluid whose base is equal to the area of the surface, and height that due to the given velocity, multiplied into the cube of the natural sine of the angle of incidence.

Let AB in the annexed figure be the horizontal projection of the given plane, which we suppose to be vertical, and moving in the direction and with the velocity BC; and draw CD perpendicular to AB. The pressure on the given surface is by the former theorem proportional to the square of its velocity through the fluid in a direction perpendicular to itself: this velocity is here represented by the line CD, for the pressure is precisely the same as it would be if the surface moved in the direction of that line, and with a velocity equal to its length. Thus, calling v the velocity BC, i the angle of incidence ABC, and p the pressure on the surface perpendicular to its plane, $p = a \frac{v^2 \sin. i^2}{2g}$, and the resistance in the direction CB, which is equal to $p \sin. i$, $= a \frac{v^2 \sin. i^3}{2g}$.



The power required to overcome this resistance with the velocity v , being equal to the moment of the resistance or the pressure multiplied into the velocity, is $a \frac{v^2 \sin. i^3}{2g} v$ or $a \frac{v^3 \sin. i^3}{2g}$, which is the same as if the surface moved perpendicularly to itself with the velocity $v \sin. i$. This may therefore be called the *effective velocity* of the surface.

PADDLE-WHEELS WITH FIXED FLOATS.

THE COMMON WHEEL.

The construction of this wheel is so simple and so well known, that a description of it here would be superfluous, having already referred to the diagram Plate I. Fig. 1, which is sufficient for our present purpose; we shall therefore proceed at once to investigate the action of the floats (which, for the sake of simplicity, we shall suppose to be perfectly radial) during their motion through the water.

Let R be the extreme radius of the wheel, r the radius to the inner edge of the floats, a the height of the axis above the level of the water, ϕ the angle which the surface of one of the floats makes with the vertical at any given instant, x the distance of a given point of the surface from the axis, V its *circumferential velocity*, and v the velocity of the vessel, all the measurements being given in feet, and the velocities in feet per second. The velocity of the given point through the water in a direction perpendicular to the surface of the float, which we have called its *effective velocity*, is equal to $V - v \cos. \phi$; for in the figure page 13, A being the given point, its effective velocity is AE ; and, the angle ABG being equal to ACD which is equal to ϕ , and AB being equal to V and BG to v , we have

$$AE = AB - BE = V - v \cos. \phi.$$

Let n be the number of revolutions of the wheel per minute, and ρ the radius of the *rolling circle*; the distance travelled by the vessel in a minute $= 60v = 2\pi\rho n$, whence $v = \frac{\pi\rho n}{30}$.

In like manner $V = \frac{\pi x n}{30}$. These values being substituted in the expression of the *effective velocity*, it becomes

$$\frac{\pi n}{30} [x - \rho \cos. \phi].$$

The factor $x - \rho \cos. \phi$ is the distance of the given point from the point F (V. Fig. page 12).

Let b be the breadth of the float, then $b \cdot dx$ will be the area of an element of its surface extending from one side to the other, and the resistance opposed to its motion, according to the theory already laid down, will be equal to

$$\frac{\pi^2 n^2 b w}{900 \times 2g} [x - \rho \cos. \phi]^2 dx,$$

w being the weight of a cubic foot of water.

If we multiply this expression into the *circumferential velocity* of the element of surface, we have already shown that the product will be the power expended upon it, or the differential of the power expended upon the surface of the float while in the given position. We have therefore, calling p this latter quantity,

$$dp = \frac{\pi^3 n^3 b w}{27000 \times 2g} [x - \rho \cos. \phi]^2 x dx;$$

and supposing the upper edge of the float not to be immersed below the surface of the water, in which case the limits of the values of x are R and $\frac{a}{\cos. \phi}$,

$$\begin{aligned} p &= \frac{\pi^3 n^3 b w}{27000 \times 2g} \int_{\frac{a}{\cos. \phi}}^R [x - \rho \cos. \phi]^2 x \cdot dx \\ &= \frac{\pi^3 n^3 b w}{27000 \times 2g} \left(\frac{1}{4} R^4 - \frac{2}{3} R^3 \rho \cos. \phi + \frac{1}{2} R^2 \rho^2 \cos. \phi^2 - \frac{1}{4} \frac{a^4}{\cos. \phi^4} + \frac{2}{3} \frac{a^3 \rho}{\cos. \phi^2} - \frac{1}{2} a^2 \rho^2 \right). \end{aligned}$$

If we call P the mean power expended on the float during a whole revolution, on the supposition that it is never immersed above its upper edge, and a the angle at which it enters and leaves the water, we shall have

$$P = \frac{\pi^3 n^3 b w}{324000 \times 2g} \int_0^a [3R^4 - 8R^3 \rho \cos. \phi + 6R^2 \rho^2 \cos. \phi^2 - \frac{3a^4}{\cos. \phi^4} + \frac{8a^3 \rho}{\cos. \phi^2} - 6a^2 \rho^2] d\phi.$$

By integration we find, after simplifying,

$$P = \frac{\pi^3 n^3 b w}{324000 \times 2g} \left([3R^4 + 3R^2 \rho^2 - 6a^2 \rho^2] a - [8R^3 \rho + R^3 a + 2Ra^3 - 3Ra\rho^2 - 8Ra^2 \rho] \sin. a \right).$$

In cases where the upper edge of the float is immersed during a part of the stroke to a certain depth below the surface of the water, the above value of P includes the power which would be expended on a paddle-board extending from the upper edge of the actual float to the surface of the water at the deepest immersion of the radius. This quantity, which is to be deducted from the former, is found by substituting in the value of P , r for R , and β for a , β being the angle at which the upper edge of the float enters and leaves the water. The difference multiplied by $2m$, the number of floats in the two wheels, will express the power expended upon them in lbs. raised one foot per second, which is reduced to horse-powers by multiplying by 60, the number of seconds in a minute, and dividing by 33000. We find thus for the general expression of the power of the engines of a steam vessel transmitted to the paddle-wheels,

$$\begin{aligned} \text{H.P.} &= \frac{\pi^2 n^3 b w m}{89100000 \times 2g} \left\{ [3R^4 + 3R^2 \rho^2 - 6a^2 \rho^2] a - [8R^3 \rho + R^3 a + 2Ra^3 - 3Ra\rho^2 - 8Ra^2 \rho] \sin. a \right. \\ &\quad \left. - [3r^4 + 3r^2 \rho^2 - 6a^2 \rho^2] \beta + [8r^3 \rho + r^3 a + 2ra^3 - 3ra\rho^2 - 8ra^2 \rho] \sin. \beta \right\} \dots (1) \end{aligned}$$

To find the portion of this power which is effective in propelling the vessel, we must first find the mean horizontal pressure on the floats, which, multiplied into the velocity of the vessel, will be equal to the effective power required.

The horizontal pressure on one of the floats in any given position is equal to the product of the total pressure by the cosine of its inclination, or

$$\frac{\pi^2 n^2 b w}{900 \times 2g} \int_{\frac{a}{\cos. \phi}}^R [x - \rho \cos. \phi]^2 \cos. \phi dx.$$

This is equal to

$$\frac{\pi^2 n^2 b w}{900 \times 2g} \left(\frac{1}{3} R^3 \cos. \phi - R^2 \rho \cos. \phi^2 + R \rho^2 \cos. \phi^3 - \frac{1}{3} \frac{a^3}{\cos. \phi^2} + a^2 \rho - a \rho^2 \cos. \phi^2 \right),$$

the mean value of which during an entire revolution is

$$\frac{\pi n^2 b w}{2700 \times 2g} \int_0^a \left(R^3 \cos. \phi - 3 R^2 \rho \cos. \phi^2 + 3 R \rho^2 \cos. \phi^3 - \frac{a^3}{\cos. \phi^2} + 3 a^2 \rho - 3 a \rho^2 \cos. \phi^2 \right) d\phi.$$

Integrating and simplifying, we find the mean horizontal pressure on one of the floats, supposed to extend to the surface of the water, to be equal to

$$\frac{\pi n^2 b w}{5400 \times 2g} \left\{ \left(6 a^2 \rho - 3 R^2 \rho - 3 a \rho^2 \right) a + \left(2 R^3 + 4 R \rho^2 - 3 R a \rho - 2 R a^2 - a \rho^2 \cos. a \right) \sin. a \right\}.$$

The quantity to be deducted in cases where the float is immersed above its upper edge is found in the same manner as it was done for the total power, and the remainder, which then expresses in lbs. the mean horizontal pressure on one of the floats, multiplied into the velocity of the vessel, which is equal to $2 \pi \rho n$, in feet per minute, will give the propelling effect due to the float in lbs. raised one foot per minute. We have thus,

$$\begin{aligned} \text{E. P.} = \frac{\pi^2 n^3 b w \rho}{2700 \times 2g} & \left\{ \left(6 a^2 \rho - 3 R^2 \rho - 3 a \rho^2 \right) a + \left(2 R^3 + 4 R \rho^2 - 3 R a \rho - 2 R a^2 - a \rho^2 \cos. a \right) \sin. a \right. \\ & \left. - \left(6 a^2 \rho - 3 r^2 \rho - 3 a \rho^2 \right) \beta - \left(2 r^3 + 4 r \rho^2 - 3 r a \rho - 2 r a^2 - a \rho^2 \cos. \beta \right) \sin. \beta \right\}. \end{aligned}$$

Multiplying by $2 m$, and dividing by 33000, we find, for the general expression of the effective power, or that portion of the power of the engines which is employed in propelling the vessel,

$$\begin{aligned} \text{H.P.E.} = \frac{\pi^2 n^3 b w \rho m}{44550000 \times 2g} & \left\{ \left(6 a^2 \rho - 3 R^2 \rho - 3 a \rho^2 \right) a + \left(2 R^3 + 4 R \rho^2 - 3 R a \rho - 2 R a^2 - a \rho^2 \cos. a \right) \sin. a \right. \\ & \left. - \left(6 a^2 \rho - 3 r^2 \rho - 3 a \rho^2 \right) \beta - \left(2 r^3 + 4 r \rho^2 - 3 r a \rho - 2 r a^2 - a \rho^2 \cos. \beta \right) \sin. \beta \right\} \quad \dots (2) \end{aligned}$$

The mode of applying these formulæ will be illustrated by the following example:

The wheels of Her Majesty's steam frigate 'Salamander' are 21 feet in diameter, the paddle-boards 8 feet 9 inches broad and 2 feet 6 inches deep, and there are sixteen on each wheel. Thus $R = 10.5$, $r = 8$, $b = 8.75$, and $m = 16$. When tried at Woolwich, the greatest immersion of the floats was 5 feet 6 inches, the number of strokes made by the engines was 15, and the speed 8.15 statute miles per hour. We have therefore $a =$ the height of the axis of the wheel above the surface of the water $= 5$, $n = 15$, and $\rho = \frac{88 \times 8.15}{2 \pi n} = \frac{358.6}{\pi n}$. The angles a and β and their sines are easily found in Tables of logarithms, knowing that $\cos. a = \frac{a}{R}$ and $\cos. \beta = \frac{a}{r}$.

We will first apply the formula (1) to find the total power transmitted to the wheels, which is most conveniently done by means of logarithms. We find

$$\text{Log. } R = 1.0211893$$

$$\text{Log. } r = 0.9030900$$

$$\text{Log. } a = 0.6989700$$

$$\text{Log. } \rho = 0.8813691$$

$$\text{Log. } \pi = 0.4971499$$

$$\text{Log. } n = 1.1760913$$

$$\text{Log. } b = 0.9420081$$

$$\text{Log. } m = 1.2041200$$

We have assumed $w = 64.125$, which is the weight of a cubic foot of sea water, and $2g$, which is the velocity of a falling body at the end of the first second, is equal to 64.38 . We find therefore,

$$\text{Log. } w = 1.8070274,$$

$$\text{Log. } 2g = 1.8087510,$$

$\text{Log. } \cos. a = \text{Log. } a - \text{Log. } R = -1.6777807$, and the corresponding angle given in the Table of sines and cosines is $61^\circ 33' 47'' \cdot 2$, and the logarithm of the sine of this angle is found to be equal to -1.9441579 . The length of the arc a is equal to 1.074479 , radius being taken as unity, and its logarithm is consequently 0.0311979 . In the same manner we find by subtracting $\text{log. } r$ from $\text{log. } a$, $\cos. \beta = -1.7958800$, whence $\beta = 51^\circ 19' 4'' \cdot 14 = 0.8956649$, and $\text{log. } \beta = -1.9521455$, also $\text{log. } \sin. \beta = -1.8924424$. We shall first find the value of the sum of the terms included between the brackets, and then perform the multiplication, by means of logarithms.

Log.	3	=	0.47712	Log.	$6 a^2 \rho^2$	=	3.93883
„	R^4	=	4.08476	„	a	=	0.03120
„	a	=	0.03120	„	$6 a^2 \rho^2 \alpha$	=	3.97003
„	$3 R^4 a$	=	4.59308	„	8	=	0.90309
„	$3 R^4 a$	=	39181	„	R^3	=	3.06357
„	3	=	0.47712	„	ρ	=	0.88137
„	R^2	=	2.04238	„	$\sin. a$	=	-1.94416
„	ρ^2	=	1.76274	„	$8 R^3 \rho \sin. a$	=	4.79219
„	a	=	0.03120	„	$8 R^3 \rho \sin. a$	=	61970
„	$3 R^2 \rho^2 a$	=	4.31344	„	R^3	=	3.06357
„	$3 R^2 \rho^2 a$	=	20580	„	a	=	0.69897
„	3	=	0.47712	„	$\sin. \alpha$	=	-1.94416
„	R	=	1.02119	„	$R^3 a \sin. \alpha$	=	3.70670
„	a	=	0.69897	„	$R^3 a \sin. \alpha$	=	5090
„	ρ^2	=	1.76274	„	2	=	0.30103
„	$\sin. a$	=	-1.94416	„	R	=	1.02119
„	$3 R a \rho^2 \sin. a$	=	3.90418	„	a^3	=	2.09691
„	$3 R a \rho^2 \sin. a$	=	8020	„	$\sin. \alpha$	=	-1.94416
„	8	=	0.90309	„	$2 R a^3 \sin. \alpha$	=	3.36329
„	R	=	1.02119	„	$2 R a^3 \sin. \alpha$	=	2308
„	a^2	=	1.39794	„	3	=	0.47712
„	ρ	=	0.88137	„	r^4	=	3.61236
„	$\sin. \alpha$	=	1.94416	„	β	=	-1.95215
„	$8 R a^2 \rho \sin. a$	=	4.14775	„	$3 r^4 \beta$	=	4.04163
„	$8 R a^2 \rho \sin. a$	=	14052	„	$3 r^4 \beta$	=	11006
„	6	=	0.77815	„	3	=	0.47712
„	a^2	=	1.39794	„	r^2	=	1.80618
„	ρ^2	=	1.76274	„	ρ^2	=	1.76274
„	β	=	-1.95215	„	β	=	-1.95215
„	$6 a^2 \rho^2 \beta$	=	3.89098	„	$3 r^2 \rho^2 \beta$	=	3.99819
„	$6 a^2 \rho^2 \beta$	=	7780	„	$3 r^2 \rho^2 \beta$	=	9958

Log.	8	=	0.90309	Log.	3	=	0.47712
"	r^3	=	2.70927	"	r	=	0.90309
"	ρ	=	0.88137	"	a	=	0.69897
"	$\sin. \beta$	=	-1.89244	"	ρ^2	=	1.76274
"	$8 r^3 \rho \sin. \beta$	=	4.38617	"	$\sin. \beta$	=	-1.89244
"	$8 r^3 \rho \sin. \beta$	=	24332	"	$3 r a \rho^2 \sin. \beta$	=	3.73436
"	r^3	=	2.70927	"	$3 r a \rho^2 \sin. \beta$	=	5425
"	a	=	0.69897	"	8	=	0.90309
"	$\sin. \beta$	=	-1.89244	"	r	=	0.90309
"	$r^3 a \sin. \beta$	=	3.30068	"	a^2	=	1.39794
"	$r^3 a \sin. \beta$	=	1998	"	ρ	=	0.88137
"	2	=	0.30103	"	$\sin. \beta$	=	-1.89244
"	r	=	0.90309	"	$8 r a^2 \rho \sin. \beta$	=	3.97793
"	a^3	=	2.09691	"	$8 r a^2 \rho \sin. \beta$	=	9505
"	$\sin. \beta$	=	-1.89244				
"	$2 r a^3 \sin. \beta$	=	3.19347				
"	$2 r a^3 \sin. \beta$	=	1561				
	Sum of positive terms	=	117504				
					Sum of negative terms	=	114595
					Sum of positive terms	=	117504
							2909

Log.	2909	=	3.46377
"	π^2	=	0.99430
"	n^3	=	3.52827
"	b	=	0.94201
"	w	=	1.80703
"	m	=	1.20412
"	1	=	-8.05012
"	$\frac{1}{89100000}$	=	-2.19125
"	$\frac{1}{2g}$	=	

$$\text{Log. H.P.} = 2.18087 \quad \text{H.P.} = 151.66.$$

The nominal power of the engines is 220 horse-power at 22 revolutions per minute; therefore the nominal power with only 15 revolutions is 150 horse-power;¹ so that in this case the calculated power surpasses the nominal power by very little more than one per cent. In this calculation some of the resistance has been neglected, viz. that on the arms and the edges of the floats, to which should also be added the effect of the back water and the shock, the amount of which we cannot at present estimate; but as the engines are supposed to work above their nominal power, and it is not known by how much, the above result may be very near the truth.

The following is the calculation of the effective power according to the formula (2).

Log.	6	=	0.77815	Log.	3	=	0.47712
"	a^2	=	1.39794	"	R^2	=	2.04238
"	ρ	=	0.88137	"	ρ	=	0.88137
"	a	=	0.03120	"	a	=	0.03120
"	$6 a^2 \rho a$	=	3.08866	"	$3 R^2 \rho a$	=	3.43207
"	$6 a^2 \rho a$	=	1226.5	"	$3 R^2 \rho a$	=	2704.4

¹ If, with a given evaporation, the effect of the engines were 220 horse-power at 22 revolutions per minute, it is evident that it would be considerably more at 15 revolutions, instead of being less.—ED.

Log. 2 = 0.30103	Log. 3 = 0.47712
" R ³ = 3.06357	" a = 0.69897
" sin. α = -1.94416	" ρ ² = 1.76274
	" a = 0.03120
" 2 R ³ sin. α = 3.30876	" 3 a ρ ² α = 2.97003
" 2 R ³ sin. α = 2035.9	" 3 a ρ ² α = 933.3
" 4 = 0.60206	" 3 = 0.47712
" R = 1.02119	" R = 1.02119
" ρ ² = 1.76274	" a = 0.69897
" sin. α = -1.94416	" ρ = 0.88137
	" sin. α = -1.94416
" 4 R ρ ² sin. α = 3.33015	" 3 R a ρ sin. α = 3.02281
" 4 R ρ ² sin. α = 2138.7	" 3 R a ρ sin. α = 1053.9
" 3 = 0.47712	" 2 = 0.30103
" r ² = 1.80618	" R = 1.02119
" ρ = 0.88137	" a ² = 1.39794
" β = -1.95215	" sin. α = -1.94416
" 3 r ² ρ β = 3.11682	" 2 R a ² sin. α = 2.66432
" 3 r ² ρ β = 1308.6	" 2 R a ² sin. α = 461.7
" 3 = 0.47712	" a = 0.69897
" a = 0.69897	" ρ ² = 1.76274
" ρ ² = 1.76274	" cos. α = -1.67778
" β = -1.95215	" sin. α = -1.94416
" 3 a ρ ² β = 2.89098	" a ρ ² cos. α sin. α = 2.08365
" 3 a ρ ² β = 778.0	" a ρ ² cos. α sin. α = 121.2
" 3 = 0.47712	" 6 = 0.77815
" r = 0.90309	" a ² = 1.39794
" a = 0.69897	" ρ = 0.88137
" ρ = 0.88137	" β = -1.95215
" sin. β = -1.89244	" 6 a ² ρ β = 3.00961
" 3 r a ρ sin. β = 2.85299	" 6 a ² ρ β = 1022.4
" 3 r a ρ sin. β = 712.8	" 2 = 0.30103
" 2 = 0.30103	" r ³ = 2.70927
" r = 0.90309	" sin. β = -1.89244
" a ² = 1.39794	" 2 r ³ sin. β = 2.90274
" sin. β = -1.89244	" 2 r ³ sin. β = 799.4
" 2 r a ² sin. β = 2.49450	" 4 = 0.60206
" 2 r a ² sin. β = 312.2	" r = 0.90309
" a = 0.69897	" ρ ² = 1.76274
" ρ ² = 1.76274	" sin. β = -1.89244
" cos. β = -1.79588	" 4 r ρ ² sin. β = 3.16033
" sin. β = -1.89244	" 4 r ρ ² sin. β = 1446.5
" a ρ ² cos. β sin. β = 2.15003	" a ρ ² cos. β sin. β = 141.3
" a ρ ² cos. β sin. β = 141.3	Sum of negative terms . . . = 8542.8
Sum of positive terms . . . = 8654.0	Sum of positive terms . . . = 8654.0
	* 111.2

* On referring to the former part of this work, it will be found that the consumption of coals by the 'Salamander' is given at 2 tons per hour; and assuming that 8 lbs. of coals evaporate 1 cubic foot of water, the evaporation amounts to $4\frac{2}{3}$ cubic feet of water per minute for each engine: the result given above must therefore be far inferior to the actual fact.—Ed.

Log.	111.2	=	2.04610
"	π^2	=	0.99430
"	n^3	=	3.52827
"	b	=	0.94201
"	w	=	1.80703
"	ρ	=	0.88137
"	m	=	1.20412
"	1	=	-8.35115
"	44550000	=	
"	$\frac{1}{2g}$	=	-2.19125
Log.	H.P.E.	=	1.94560
	H.P.E.	=	88.23.

Thus a power of 88.23 horses is sufficient, if applied immediately to the vessel; but 151.66 horse-powers are required to be applied to the wheels to produce the same propelling effect, the proportion of the effective to the total power being as 0.582 to 1. This shows the loss of power at deep immersions to be very great, even without considering the effects of the shock and back water; it amounts in the above example to more than 63 horse-power, or about 41.8 per cent. of the whole power transmitted to the wheels.

It is obvious, that at light immersions, when the upper edge of the float is never under water, all the terms in which β or $\sin. \beta$ enters as a factor disappear, and only one-half of the number of terms remain; and even if the float is immersed a few inches above its upper edge at the middle of the stroke, the amount of those terms is so small, that they may be neglected without causing any material error in the result. For example, if $a = \frac{15}{16}r$ and $\rho = \frac{7}{8}r$, the error is about one per cent.; but if $\rho = a$, then the error is only about one-third per cent. Thus, the diameter of the wheel being 20 feet, the depth of the floats 2 feet, and their greatest immersion 2 feet 6 inches, or 6 inches above their upper edge, the resistance would not be more than one per cent. less than if the floats were made 2 feet 6 inches in depth, so as to reach the surface of the water. We here suppose the radius of the *rolling circle* to be 7 feet; if it were only 6 feet the error would be a little more considerable, but not much, for if the immersion were 3 feet and the radius of the *rolling circle* 6 feet, the error would not exceed 2 per cent.

The power expended on the wheels of a steam vessel would be found much more readily if we knew the position of the *centre of pressure*, but we are not aware of any direct method of finding that point.

By *centre of pressure* is understood a point on the surface of the paddle-board at such a distance from the axis of the wheel, that if the whole surface of the board were concentrated in that point, or in the horizontal line passing through it, the mean resistance would not be affected by the change; it does not, however, follow that the effective resistance would remain unaltered, so that this point is only the centre of total pressure, and not of effective pressure; nor is it the centre of pressure of the float in any given position, but the mean for all the positions taken by the float during its passage through the water, and should therefore, strictly speaking, be called the mean centre of pressure; but as it is already known as the

centre of pressure, we will retain this expression for the sake of brevity. The position of this point being known, we can find the power in the following manner :

Let y be the distance of the *centre of pressure* from the axis of the wheel, θ the angle at which it enters and leaves the water, a , b , ρ , n and m , the same as in the former calculations, and f the depth of the float. The pressure on the float at any angle ϕ is equal to the product of its area $b f$, by the square of its *effective velocity* and the weight of a cubic foot of water, divided by $2 g$. The *effective velocity* of the float is equal to

$$\frac{\pi n}{30} [y - \rho \cos. \phi],$$

so that the pressure is equal to $\frac{\pi^2 n^2 b f w}{900 \times 2 g} [y - \rho \cos. \phi]^2$,

and the moment of the resistance to $\frac{\pi^3 n^3 b f w}{27000 \times 2 g} [y - \rho \cos. \phi]^2 y$.

The mean value of this expression is equal to the definite integral

$$\frac{\pi^2 n^3 b f w}{27000 \times 2 g} \int_0^\theta [y - \rho \cos. \phi]^2 y \cdot d\phi,$$

which is $\frac{\pi^2 n^3 b f w}{54000 \times 2 g} \left\{ [2y^3 + y\rho^2] \theta + [a\rho^2 - 4y^2\rho] \sin. \theta \right\}$.

This multiplied by $2 m$, and reduced to horse-powers, becomes

$$\frac{\pi^2 n^3 b f w m}{14850000 \times 2 g} \left\{ [2y^3 + y\rho^2] \theta + [a\rho^2 - 4y^2\rho] \sin. \theta \right\} = \text{H. P.} \quad (3)$$

The first member of this equation being equal to the second member of the equation (1) (page 17), it is evident that the sum of the terms between the brackets in the former, multiplied by $6 f$, must be equal to the sum of the terms between brackets in the latter, or, calling S that sum in formula (1), and S'' the sum in formula (3), we must have

$$S'' = \frac{S}{6f}.$$

Having first found the value of S , and assumed a value of y not very far from the truth, we can prove it with very little trouble by the above formula. If we find too great a value for S'' , we take off a little from our assumed value of y , and if the second result differ still from the true value of S'' , we make a proportion of the differences; the third result will be as near as can be desired, if the differences are small. In this manner the following Tables were calculated, in which the extreme radius of the wheel has been assumed equal to 10, or, which is the same thing, one-tenth of the radius has been taken as unity. The immersion is given in the upper line, and the radius of the rolling circle in the first column on the left; the decimal fraction corresponding to the given immersion and radius of the rolling circle expresses the portion of the depth of the float included between its upper edge and its *centre of pressure*. Thus, if the immersion be 4, and the radius of the rolling circle 7.4 (see Table I.), the *centre of pressure* will be situated at a distance of 0.557 of the depth of the float from its upper edge.

TABLE I.—Extreme radius = 10; Depth of float = 2.

Radius of the Rolling Circle.	DIP OF THE FLOAT.														
	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50
8.0	0.607	0.599	0.593	0.587	0.582	0.577	0.573	0.569	0.566	0.563	0.560	0.557	0.555	0.552	0.550
7.9	0.603	0.596	0.590	0.584	0.579	0.575	0.571	0.567	0.564	0.561	0.559	0.556	0.554	0.551	0.549
7.8	0.599	0.593	0.587	0.582	0.577	0.573	0.569	0.566	0.563	0.560	0.557	0.555	0.553	0.550	0.548
7.7	0.595	0.589	0.584	0.579	0.574	0.570	0.567	0.564	0.561	0.558	0.556	0.554	0.552	0.549	0.547
7.6	0.592	0.586	0.581	0.576	0.572	0.568	0.565	0.562	0.559	0.557	0.555	0.553	0.551	0.548	0.546
7.5	0.588	0.583	0.578	0.574	0.570	0.566	0.563	0.560	0.558	0.556	0.554	0.552	0.550	0.548	0.546
7.4	0.585	0.580	0.576	0.572	0.568	0.565	0.562	0.559	0.557	0.554	0.552	0.550	0.549	0.547	0.545
7.3	0.582	0.578	0.574	0.570	0.566	0.563	0.560	0.557	0.555	0.553	0.551	0.549	0.548	0.546	0.544
7.2	0.580	0.575	0.571	0.567	0.564	0.561	0.559	0.556	0.554	0.552	0.550	0.548	0.547	0.545	0.544
7.1	0.577	0.573	0.569	0.566	0.563	0.560	0.557	0.555	0.553	0.551	0.549	0.547	0.546	0.544	0.543
7.0	0.574	0.570	0.567	0.564	0.561	0.559	0.556	0.554	0.552	0.550	0.548	0.546	0.545	0.544	0.542
6.9	0.572	0.568	0.565	0.562	0.560	0.557	0.555	0.553	0.551	0.549	0.547	0.545	0.544	0.543	0.541
6.8	0.570	0.566	0.563	0.560	0.558	0.556	0.554	0.552	0.550	0.548	0.546	0.545	0.543	0.542	0.540
6.7	0.568	0.564	0.561	0.559	0.557	0.555	0.553	0.551	0.549	0.547	0.545	0.544	0.543	0.541	0.540
6.6	0.565	0.562	0.560	0.558	0.556	0.554	0.552	0.550	0.548	0.546	0.544	0.543	0.542	0.540	0.539
6.5	0.563	0.561	0.559	0.557	0.555	0.553	0.551	0.549	0.547	0.545	0.544	0.542	0.541	0.540	0.538
6.4	0.561	0.559	0.557	0.555	0.553	0.551	0.550	0.548	0.546	0.545	0.543	0.542	0.541	0.539	0.538
6.3	0.559	0.557	0.555	0.553	0.552	0.550	0.549	0.547	0.546	0.544	0.543	0.541	0.540	0.538	0.537
6.2	0.558	0.556	0.554	0.552	0.551	0.549	0.548	0.546	0.545	0.543	0.542	0.540	0.539	0.538	0.536
6.1	0.556	0.554	0.553	0.551	0.550	0.548	0.547	0.545	0.544	0.542	0.541	0.540	0.539	0.537	0.535
6.0	0.554	0.553	0.551	0.550	0.549	0.547	0.546	0.544	0.543	0.542	0.541	0.539	0.538	0.536	0.535

TABLE II.—Extreme radius = 10; Depth of float = 2.5.

Radius of the Rolling Circle.	DIP OF THE FLOAT.												
	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50
7.5	0.607	0.601	0.596	0.591	0.587	0.583	0.579	0.576	0.573	0.570	0.567	0.564	0.562
7.4	0.604	0.599	0.594	0.589	0.585	0.581	0.577	0.574	0.571	0.568	0.565	0.563	0.561
7.3	0.601	0.596	0.591	0.587	0.583	0.579	0.576	0.572	0.569	0.566	0.564	0.562	0.560
7.2	0.598	0.593	0.589	0.585	0.581	0.578	0.574	0.571	0.568	0.565	0.563	0.561	0.559
7.1	0.595	0.590	0.586	0.582	0.579	0.576	0.573	0.570	0.567	0.564	0.562	0.560	0.558
7.0	0.592	0.588	0.584	0.581	0.578	0.574	0.571	0.568	0.566	0.563	0.561	0.559	0.557
6.9	0.590	0.586	0.582	0.579	0.576	0.573	0.570	0.567	0.564	0.562	0.560	0.558	0.556
6.8	0.587	0.583	0.580	0.577	0.574	0.571	0.568	0.565	0.563	0.561	0.559	0.557	0.555
6.7	0.585	0.581	0.578	0.575	0.572	0.569	0.567	0.564	0.562	0.560	0.558	0.556	0.554
6.6	0.583	0.579	0.576	0.573	0.570	0.568	0.565	0.563	0.561	0.559	0.557	0.555	0.553
6.5	0.580	0.577	0.574	0.571	0.569	0.566	0.564	0.562	0.560	0.558	0.556	0.554	0.552
6.4	0.578	0.575	0.572	0.570	0.567	0.565	0.563	0.560	0.558	0.557	0.555	0.553	0.551
6.3	0.576	0.573	0.570	0.568	0.566	0.563	0.561	0.559	0.557	0.555	0.554	0.552	0.551
6.2	0.574	0.571	0.569	0.566	0.564	0.562	0.560	0.558	0.556	0.554	0.553	0.551	0.550
6.1	0.572	0.569	0.567	0.565	0.563	0.561	0.559	0.557	0.555	0.553	0.552	0.550	0.549
6.0	0.570	0.568	0.566	0.563	0.561	0.560	0.558	0.556	0.554	0.552	0.551	0.549	0.548
5.9	0.568	0.566	0.564	0.562	0.560	0.558	0.557	0.555	0.553	0.551	0.550	0.548	0.547
5.8	0.566	0.564	0.562	0.560	0.559	0.557	0.556	0.554	0.552	0.550	0.549	0.548	0.546
5.7	0.564	0.562	0.561	0.559	0.558	0.556	0.555	0.553	0.551	0.549	0.548	0.547	0.546
5.6	0.563	0.561	0.560	0.558	0.557	0.555	0.554	0.552	0.550	0.548	0.547	0.546	0.545
5.5	0.562	0.560	0.559	0.557	0.556	0.554	0.553	0.551	0.549	0.547	0.546	0.546	0.545

The following is a type of the calculation of the power by means of the *centre of pressure*. Let it be required to find the power exerted by the engines of the 'Salamander' in the case proposed at page 18.

The radius of the paddle-wheels being 10 feet 6 inches, the position of the centre of pressure cannot be found immediately by referring to either of the preceding Tables, in which the radius is assumed equal to 10: we must therefore first find the numbers which represent in the Tables the depth and immersion of the floats, and the radius of the rolling circle. The depth of the float is represented by the number 2.38, the immersion by the number 5.238, and the radius of the rolling circle by 7.247. The depth of the float being intermediate between those assumed in the Tables, we must first enter Table I.; and in the column under the immersion 5.25, and opposite to the numbers 7.2 and 7.3, in the first column on the

left, we find the numbers 0.545, 0.546, of which we take the mean, 0.5455; then in Table II. we do the same, and find 0.561 and 0.562, of which we take the mean, 0.5615. The difference between 0.5455 and 0.5615, or 0.016, corresponding to a difference of 0.5 in the depth of the float, we find the difference corresponding to 0.38 by the proportion $0.5 : 0.016 :: 0.38 : 0.012$, sufficiently near for our purpose, and this added to 0.5455 gives 0.5575 for the proportion of the depth of the float contained between its upper edge and the centre of pressure: the distance of this point from the axis of the wheel, or y , is therefore equal to 9.3937 feet.

Log.	a	=	0.6989700
„	ρ	=	0.8813691
„	y	=	0.9728367
„	θ	=	0.0041126
„	$\sin. \theta$	=	- 1.9276647

Whence,

Log.	$2 y^3 \theta$	=	3.2236527	$2 y^3 \theta$	=	1673.60
„	$\rho^2 y \theta$	=	2.7396875	$\rho^2 y \theta$	=	549.15
„	$a \rho^2 \sin. \theta$	=	2.3893729	$a \rho^2 \sin. \theta$	=	245.12
						2467.87
„	$4 \rho y^2 \sin. \theta$	=	3.3567672	$4 \rho y^2 \sin. \theta$	=	2273.88
				S''	=	193.99

Log.	S''	=	2.2877771
„	π^2	=	0.9942998
„	n^3	=	3.5282738
„	b	=	0.9420081
„	f	=	0.3979400
„	w	=	1.8070274
„	m	=	1.2041200
„	$\frac{1}{2g}$	=	- 2.1912490
„	$\frac{1}{14850000}$	=	- 8.8282735

Log.	H.P.	=	2.1809687
	H.P.	=	151.69.

The calculation of the effective power would be abridged in the same manner by means of an analogous point, which we would call the *centre of propelling effect*. This point is so situated, that, if the whole surface of the float were concentrated there, the propelling effect would remain the same; so that, calling z the distance of this point from the axis of the wheel, and ζ the inclination of the float when its centre of propelling effect enters and leaves the water, the propelling effect of a pair of wheels may be found in the following manner:

We know the total pressure on one of the floats at the angle ϕ to be equal to

$$\frac{\pi^2 n^2 b f w}{900 \times 2g} (z - \rho \cos. \phi)^2,$$

whence the horizontal or effective pressure is equal to

$$\frac{\pi^2 n^2 b f w}{900 \times 2g} [z - \rho \cos. \phi]^2 \cos. \phi,$$

the mean value of which is

$$\frac{\pi n^2 b f w}{900 \times 2g} \int_0^{\zeta} [z - \rho \cos. \phi]^2 \cos. \phi \cdot d\phi,$$

or,

$$\frac{\pi n^2 b f w}{2700 \times 2g} \left\{ [3z^2 + 2\rho^2 + \rho^2 \cos. \zeta^2 - 3a\rho] \sin. \zeta - 3\rho z \zeta \right\}.$$

The mean effective pressure on the two wheels, which is equal to the resistance opposed to the motion of the vessel, is therefore

$$\frac{\pi n^2 b f w m}{1350 \times 2g} \left\{ [3z^2 + 2\rho^2 + \rho^2 \cos. \zeta^2 - 3a\rho] \sin. \zeta - 3\rho z \zeta \right\}.$$

Multiplying this by $\frac{\pi \rho n}{30}$, the velocity of the vessel in feet per second, we find the propelling power in lbs. moved through one foot in a second to be equal to

$$\frac{\pi^2 n^3 b f w m \rho}{40500 \times 2g} \left\{ [3z^2 + 2\rho^2 + \rho^2 \cos. \zeta^2 - 3a\rho] \sin. \zeta - 3\rho z \zeta \right\},$$

which, reduced to horse-powers, becomes

$$\frac{\pi^2 n^3 b f w m \rho}{22275000 \times 2g} \left\{ [3z^2 + 2\rho^2 + \rho^2 \cos. \zeta^2 - 3a\rho] \sin. \zeta - 3\rho z \zeta \right\} = \text{H.P.E.} \dots (4)$$

The first member of this equation being equal to the second member of the equation (2) (page 18), the sum of the terms between the brackets in the former, multiplied by $2f$, is equal to the sum of the terms between the brackets in the latter; or, calling S' that sum in the equation (2), and S''' that in the equation (4), we have

$$S''' = \frac{S'}{2f}.$$

The following Tables were constructed, like the two former, by assuming values for z until the equations (2) and (4) gave the same value of S''' .

TABLE III.—Extreme radius = 10 ; Depth of float = 2.

Radius of the Rolling Circle.	IMMERSION.														
	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50
8.0	0.595	0.586	0.579	0.573	0.568	0.564	0.560	0.556	0.553	0.550	0.548	0.546	0.544	0.542	0.540
7.9	0.590	0.582	0.576	0.570	0.565	0.561	0.557	0.554	0.551	0.548	0.546	0.544	0.542	0.540	0.538
7.8	0.586	0.578	0.573	0.568	0.563	0.559	0.555	0.552	0.549	0.547	0.545	0.543	0.541	0.539	0.537
7.7	0.582	0.575	0.570	0.565	0.560	0.556	0.553	0.550	0.547	0.545	0.543	0.541	0.539	0.538	0.536
7.6	0.578	0.572	0.567	0.563	0.558	0.554	0.551	0.548	0.546	0.544	0.542	0.540	0.538	0.536	0.535
7.5	0.574	0.569	0.565	0.560	0.556	0.552	0.549	0.546	0.544	0.542	0.540	0.538	0.537	0.535	0.534
7.4	0.571	0.567	0.562	0.558	0.554	0.550	0.547	0.545	0.543	0.541	0.539	0.537	0.536	0.534	0.533
7.3	0.568	0.564	0.559	0.555	0.552	0.549	0.546	0.543	0.541	0.539	0.537	0.536	0.535	0.533	0.532
7.2	0.565	0.561	0.557	0.553	0.550	0.547	0.544	0.542	0.540	0.538	0.536	0.535	0.534	0.532	0.531
7.1	0.562	0.558	0.555	0.551	0.548	0.545	0.543	0.541	0.539	0.537	0.535	0.534	0.533	0.531	0.530
7.0	0.559	0.556	0.552	0.549	0.546	0.544	0.541	0.539	0.537	0.536	0.534	0.533	0.532	0.531	0.530
6.9	0.557	0.553	0.550	0.547	0.545	0.542	0.540	0.538	0.536	0.535	0.533	0.532	0.531	0.530	0.529
6.8	0.554	0.551	0.548	0.546	0.543	0.541	0.539	0.537	0.535	0.534	0.532	0.531	0.530	0.529	0.528
6.7	0.552	0.549	0.546	0.544	0.542	0.540	0.538	0.536	0.534	0.533	0.531	0.530	0.529	0.528	0.528
6.6	0.550	0.547	0.545	0.542	0.540	0.539	0.537	0.535	0.533	0.532	0.530	0.529	0.528	0.528	0.527
6.5	0.548	0.546	0.543	0.541	0.539	0.538	0.536	0.534	0.532	0.531	0.530	0.529	0.528	0.527	0.527
6.4	0.546	0.544	0.542	0.540	0.538	0.537	0.535	0.533	0.531	0.530	0.529	0.528	0.527	0.526	0.526
6.3	0.544	0.542	0.540	0.538	0.537	0.536	0.534	0.532	0.530	0.529	0.528	0.527	0.526	0.526	0.525
6.2	0.542	0.541	0.539	0.537	0.536	0.535	0.533	0.531	0.529	0.528	0.527	0.526	0.526	0.525	0.525
6.1	0.540	0.539	0.538	0.536	0.535	0.534	0.532	0.530	0.529	0.528	0.527	0.526	0.525	0.525	0.524
6.0	0.539	0.538	0.537	0.535	0.534	0.533	0.531	0.530	0.528	0.527	0.526	0.525	0.525	0.524	0.524

TABLE IV.—Extreme radius = 10; Depth of float = 2.5.

Radius of the Rolling Circle.	IMMERSION.												
	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50
7.5	0.592	0.585	0.579	0.574	0.569	0.565	0.562	0.559	0.556	0.553	0.551	0.549	0.547
7.4	0.588	0.582	0.576	0.571	0.567	0.563	0.560	0.557	0.554	0.552	0.549	0.547	0.545
7.3	0.585	0.579	0.573	0.569	0.564	0.561	0.558	0.555	0.552	0.550	0.548	0.546	0.544
7.2	0.581	0.576	0.571	0.566	0.562	0.559	0.556	0.553	0.551	0.548	0.546	0.544	0.543
7.1	0.578	0.573	0.568	0.564	0.560	0.557	0.554	0.551	0.549	0.547	0.545	0.543	0.541
7.0	0.575	0.570	0.566	0.561	0.558	0.555	0.552	0.550	0.547	0.545	0.543	0.542	0.540
6.9	0.572	0.568	0.563	0.559	0.556	0.553	0.551	0.548	0.546	0.544	0.542	0.540	0.539
6.8	0.569	0.565	0.561	0.557	0.554	0.552	0.549	0.547	0.545	0.543	0.541	0.539	0.538
6.7	0.567	0.563	0.559	0.555	0.553	0.550	0.548	0.546	0.544	0.542	0.540	0.538	0.537
6.6	0.564	0.560	0.557	0.554	0.551	0.548	0.546	0.544	0.542	0.541	0.539	0.537	0.536
6.5	0.562	0.558	0.555	0.552	0.549	0.547	0.545	0.543	0.541	0.540	0.538	0.536	0.535
6.4	0.559	0.556	0.553	0.550	0.548	0.545	0.543	0.542	0.540	0.538	0.537	0.535	0.534
6.3	0.557	0.554	0.551	0.549	0.546	0.544	0.542	0.540	0.539	0.537	0.536	0.534	0.533
6.2	0.555	0.552	0.549	0.547	0.545	0.543	0.541	0.539	0.538	0.536	0.535	0.533	0.532
6.1	0.553	0.550	0.548	0.545	0.543	0.541	0.540	0.538	0.537	0.535	0.534	0.532	0.531
6.0	0.551	0.548	0.546	0.544	0.542	0.540	0.539	0.537	0.536	0.534	0.533	0.532	0.531
5.9	0.549	0.546	0.544	0.542	0.541	0.539	0.538	0.536	0.535	0.533	0.532	0.531	0.530
5.8	0.547	0.545	0.542	0.541	0.539	0.538	0.537	0.535	0.534	0.533	0.531	0.530	0.529
5.7	0.545	0.543	0.541	0.539	0.538	0.537	0.536	0.534	0.533	0.532	0.531	0.530	0.529
5.6	0.543	0.541	0.539	0.538	0.537	0.536	0.535	0.534	0.532	0.531	0.530	0.529	0.528
5.5	0.541	0.540	0.538	0.537	0.536	0.535	0.534	0.533	0.532	0.531	0.530	0.529	0.528

Let us now apply these Tables to the case of the 'Salamander,' for which the calculation by the other method is given in pages 20 and 21. The depth of the floats, reduced to the scale of the Tables, becomes 2.38, the immersion 5.238, and the radius of the rolling circle 7.247, as at page 25. In Table III., under the immersion 5.25, and opposite to the numbers 7.2 and 7.3 in the first column on the left, we find 0.532 and 0.533, of which we take the mean 0.5325, and in Table IV. we find the numbers 0.544 and 0.546, of which the mean is 0.545. The difference being 0.0125, we make the proportion $0.5 : 0.0125 :: 0.38 : 0.0095$, which, added to 0.5325, gives 0.542 for the proportion of the depth of the float contained between its upper edge and the centre of propelling effect, so that the distance of this point from the axis of the wheel, or z , is equal to 9.355 feet. We have thus

Log.	a	=	0.6989700
"	ρ	=	0.8813691
"	z	=	0.9710438
"	ζ	=	0.0029913
"	$\sin. \zeta$	=	-1.9269519
"	$\cos. \zeta$	=	-1.7279262

Whence,

Log.	$3z^2 \sin. \zeta$	=	2.3461608	$3z^2 \sin. \zeta$	=	221.902
"	$2\rho^2 \sin. \zeta$	=	1.9907201	$2\rho^2 \sin. \zeta$	=	97.886
"	$\rho^2 \cos. \zeta^2 \sin. \zeta$	=	1.1455425	$\rho^2 \cos. \zeta^2 \sin. \zeta$	=	13.981
Sum of positive terms					=	333.769
"	$3a\rho \sin. \zeta$	=	1.9844123	$3a\rho \sin. \zeta$	=	96.474
"	$3\rho z \zeta$	=	2.3325255	$3\rho z \zeta$	=	215.043
Sum of negative terms					=	311.517
S'''					=	22.252

Log.	S'''	=	1.3473691
"	π^2	=	0.9942998
"	n^3	=	3.5282738
"	b	=	0.9420081
"	f	=	0.3979400
"	w	=	1.8070274
"	m	=	1.2041200
"	ρ	=	0.8813691
"	$\frac{1}{2g}$	=	-2.1912490
"	$\frac{1}{22275000}$	=	-8.6521823
Log. H.P.E.		=	1.9458386
H.P.E.		=	88.275.

When a steamer is heavily laden, the wheels, from their excessive immersion, act less advantageously, besides reducing the number of strokes of the engines by the great number of floats immersed at once, and their great obliquity, which increases the resistance. Under these circumstances the speed of the vessel is naturally diminished, and it may in some cases be desirable to bring out the full power of the engines, as it is called; that is, to enable them to make the full number of strokes they were calculated for, in order to prevent so great a loss of speed. We know but one mode of effecting this, and that is by reefing the floats, or shifting them from the circumference nearer to the shaft. This method is attended at present with too much difficulty and danger to allow of its being put into general practice; but we do not presume to say that a means may not be found to facilitate the operation, so as to render it practicable.

It is very clear that the desired effect could not be produced by reducing the size of the

paddle-boards, except inasmuch as the centre of pressure is thereby brought nearer to the axis of the wheel: suppose, for example, that a piece has been cut off from the end of each board; the consequence will naturally be that the circumferential velocity of the wheel will be increased, until the mean pressure on the floats becomes equal to what it was before they were reduced. The pressure being restored, the horizontal pressure will be so too, but cannot surpass what it was before, since the ratio of the horizontal to the total pressure is independent of the breadth of the floats. The speed of the vessel must therefore remain the same, although the expenditure of fuel is increased in the ratio of the increased velocity of the engines. If, on the other hand, we suppose the floats to be reefed, then the engines will not only move so much faster that the floats shall experience the same resistance, but their velocity will increase until the mean pressure on the floats is to the former mean pressure as the former radius to the *centre of pressure* is to the new one. The total pressure being thus increased, the horizontal pressure will be so in a greater proportion, because, the angles of the floats being less oblique, the ratio of the horizontal to the total pressure will be greater; consequently, the vessel will go faster. We can only come to this general conclusion at present, as there is no method yet known of finding the precise effect of reefing the floats.

FIELD'S PADDLE-WHEEL.

The construction of this wheel is thus explained by Mr. Field:

"Each board is divided into several parts, or narrower boards, and arranged in, or nearly, such cycloidal curves, that they all enter the water at the same place in immediate succession, thus avoiding the shock produced by the entrance of the common board, so unpleasant to passengers, injurious to the vessel, and wasteful of the power. As the acting face of each board is radiating, it propels while passing under the centre in the ordinary way, and when it emerges, the water escapes simultaneously from each narrow board, and consequently cannot lop-up."

Mr. Galloway describes his invention to be exactly the same thing, but goes into geometrical details, which are not mathematically correct.

Fig. 1, Plate II., is a diagram intended to elucidate the construction of this kind of wheel. Not having any data at the time this plate was engraved, we contented ourselves with the same dimensions as those of the common wheel in Plate I., and supposing the same performances as with the latter, merely with the view of comparing their modes of action. Each board is divided into four narrow boards, *a, b, c, d*, respectively, six, seven, eight, and nine inches in depth. Figs. 2 and 4 show the path of one set of boards at the light and load draught, and figs. 3 and 5 the nodes, enlarged to four times the scale on account of the complication resulting from the number of boards in the set. On inspecting the two latter figures, the peculiarity of action arising from this disposition of the paddle-boards becomes evident, but more particularly in fig. 5, where the floats are immersed for a longer time. One set of floats is there seen entering the water at *a, b, c, d*, the position of which is shown at *a', b', c', d'*, after an interval of one-sixteenth of a revolution; and it is apparent that, while the outer board, *a*, is moving to the position *a'*, the next board, *b*, almost follows the track of the former to arrive at *b'*: in the same manner the third follows the second, and the fourth

the third, until they arrive at the middle of the stroke, when they diverge so as to perform the last half of the stroke independent of each other's motions, and emerge from the water at such a distance from each other, that the water which is not thrown off with violence can run off more readily than from the broad float of the common wheel. It thus appears that very little more effect is produced during the first half of the stroke of one set of boards than would be produced by the outer board alone, and during the second half the effect is about equal to that of a common float equal in size to the sum of those which form a set. We conclude, therefore, that the shock received by the floats on entering the water must be reduced nearly to that of the outer board, but that this advantage is gained at the expense of a considerable portion of the effect, in consequence of which the wheels must require a greater surface of paddle-board than common wheels. There may also be a little advantage in the manner the floats leave the water, but that, if any, must be very trifling. It is evident that no theoretical calculation can be made of the effect of this wheel, its action being precisely similar to that of the common wheel, except that all but the outer boards move during a considerable part of their stroke in troubled water, whereby a loss of resistance is sustained, the amount of which cannot be computed. It remains, therefore, to be decided by experience whether the disadvantages of this wheel are overbalanced by the advantages which it seems to possess.

It is remarkable that since the adoption of this wheel, when Mr. Galloway made them with six or seven *bars* in each set instead of the ordinary paddle-boards, this number has been very much reduced: those now used in Her Majesty's service have only two boards in a set, every reduction having been found to be attended with advantage; they cannot, however, carry their improvements any farther without annihilating the principle of the wheel altogether, and returning to the *common wheel*.

It should here be observed, that in the summer of the year 1837, before these wheels were adopted in Her Majesty's service, a numerous series of experiments were made at Woolwich, on Her Majesty's steamer 'African,' under the superintendence of the late Mr. Ewart, inspector of steam machinery, some with the common wheel, and some with Field's, in order to ascertain the comparative merits of the two wheels. The results of these experiments were not allowed to be publicly known, because *they were not complete*; but Mr. Ewart was so well satisfied with the success of the trials, that Her Majesty's steam vessels 'Rhadamanthus,' 'Dee,' 'Tartarus,' and 'Meteor,' were immediately fitted with Field's wheels, each with two boards in a set. From what we have been able to learn from persons who were present at the experiments alluded to, some very anomalous results were obtained, such as *less velocity of the engines and greater speed of the vessel with less float*, all other circumstances being the same.

A few trials were subsequently made with Her Majesty's steam vessel 'Tartarus,' which throw some light on the relative qualities of the wheel under consideration, and Morgan's wheel. This vessel formerly had a pair of the latter wheels with two fifty-horse engines; she afterwards had a pair of wheels with the divided floats, and made to go into the old paddle-boxes, and two seventy-horse engines. When she was tried with the former, she was ready for sea, drawing 12 feet 2 inches mean, and having an immersed midship section of about 254 square feet: the steam pressure in the boiler was $2\frac{3}{4}$ lbs., and the vacuum 27 inches. Under these circumstances a mean speed of 8.508 statute miles was obtained, the wheels

making 22 revolutions per minute. When tried in February, 1838, with Field's wheels, the mean draught was 9 feet 11 inches, making her immersed midship section about 176 square feet: the steam pressure was $5\frac{1}{4}$ lbs., and vacuum 28 inches. The mean speed was 11.11 square miles, with 32 revolutions per minute.

She was tried again on the 11th of March, with her lower masts and shrouds, having provisions and 130 tons of coal on board; she drew about 11 feet 8 inches, and the speed obtained was 8.44 miles, with 24 revolutions: the radius of *rolling circle* was consequently 4 feet 11 inches, the extreme radius of the wheels being 8 feet 5 inches, so that the *slipping through* of the floats on both these trials was quite extraordinary, and can only be accounted for by the loss of resistance in the first half of the stroke, and the want of a sufficient surface of paddle-board, which cannot be given without far surpassing the dimensions required by Morgan's wheels.

PADDLE-WHEELS WITH OBLIQUE FLOATS.

Such wheels have been tried at various times and under various forms, some of which have been patented. Among these may be named, as the most simple, that for which Mr. Samuel Hall obtained a patent in June, 1836. In this wheel the paddle-boards, instead of standing at right angles to the rims and parallel to the axis of the wheel, as in wheels of the ordinary construction, are placed obliquely to the rims and to the axis of the wheel. The subject of the patent is not, however, the use of oblique floats, but the making of one half of them to enter the water in one diagonal direction, and the other half to enter it in the reverse diagonal direction, or in large paddle-wheels making the boards change their direction of entering the water four times instead of twice. We do not think that any effect can be produced by giving the floats different positions, but that the action would be about the same as that of the ordinary paddle-wheel with oblique floats, in which they all incline the same way; and it has been found by experience that this requires a greater surface of paddle-board than the common wheel to produce the same effect, which can also be demonstrated theoretically in the following manner:

The *circumferential velocity* of any given point of a float of the common wheel being V , and the velocity of the vessel v , we have already seen that its *effective velocity* is $V - v \cos. \phi$, and that the pressure upon it is proportional to $[V - v \cos. \phi]^2$; but with the same given velocities, the *effective velocity* of a point of an oblique float, situated on the radius which passes through the middle of the float, and at the same distance from the axis as the given point in the common wheel, is only $[V - v \cos. \phi] \cos. a$, if a is the angle which the surface of the float makes with the axis of the wheel. The corresponding pressure is therefore proportional to $[V - v \cos. \phi]^2 \cos. a^2$; and, the width of the wheels being the same in both cases, the ratio of the tangential pressure on the oblique float to that on the common float is $\frac{\cos. a^2}{1}$, supposing the whole of the former to radiate from the axis, which is only true for the middle part; but that will not affect the reasoning, as it might easily be shown that there is rather a disadvantage than otherwise in the float not being radial.

PADDLE-WHEELS WITH FEATHERING FLOATS.

This class may be subdivided into,

A. Paddle-wheels with floats turning on radial axes, and

B. Paddle-wheels with floats turning on horizontal axes or spindles.

A. *Paddle-wheels with floats turning on radial axes.*

Of these very little need be said, as they have not yet been, and are not likely ever to be, adopted. The action of all of them is nearly the same: the floats either enter or leave the water, or both, in the direction of their surface, or at a very acute angle with it. The action is therefore generally *very oblique*; besides which, the mode of feathering the floats is so objectionable, that that alone would be sufficient to condemn the system. The floats are fixed to spindles radiating from the axis of the wheel, each of which is furnished with a crank at its inner extremity, through the medium of which the spindle is made to turn by means of a groove or other guide fixed to the side of the vessel (as in Symington's wheel), or in the interior of the wheel itself (as in Steed's, &c.). Time will not permit us to give a full description of any of these wheels, nor to enter into any calculation of their effect, which must, however, be quite unnecessary; for a machine tried under such favourable circumstances as Symington's wheel must certainly have been adopted, if it had any claim to preference. A wheel, on a similar principle, with the paddle-cranks guided by cams in the interior of the wheel, was tried some years ago in a small boat on the Thames; but the friction was so great that three or four men could scarcely prevent the boat from being carried down by the tide, although they could easily have rowed her at a moderate speed. The friction of the feathering machinery must in all cases be very considerable; so that, however beautifully it may work at the beginning, there is no doubt that its action would soon be impaired by wear, and it would, perhaps, not require a long time to be entirely destroyed.

B. *Paddle-wheels with floats turning on horizontal axes or spindles.*

BUCHANAN'S WHEEL.

The principle of this wheel is described by the patentee in his specification in the following manner:

"In the first place, my said invention is established upon a mathematical theorem, which may be enumerated in the words here underlined, namely: *If two equal rings or circular lines be conceived to revolve, each upon its respective centre in its own plane, with one and the same uniform velocity, and in the same direction with regard to parts of the lines or rings alike situated, and any point be taken in one of the rings or lines, and a right line be drawn from that point parallel to a line supposed to join the centres, until it meets the other line or circle, then I say the right line so drawn will be equal to the line of distance between the centres, and will continue equal and parallel to that line of distance during the whole of every revolution so made.*"

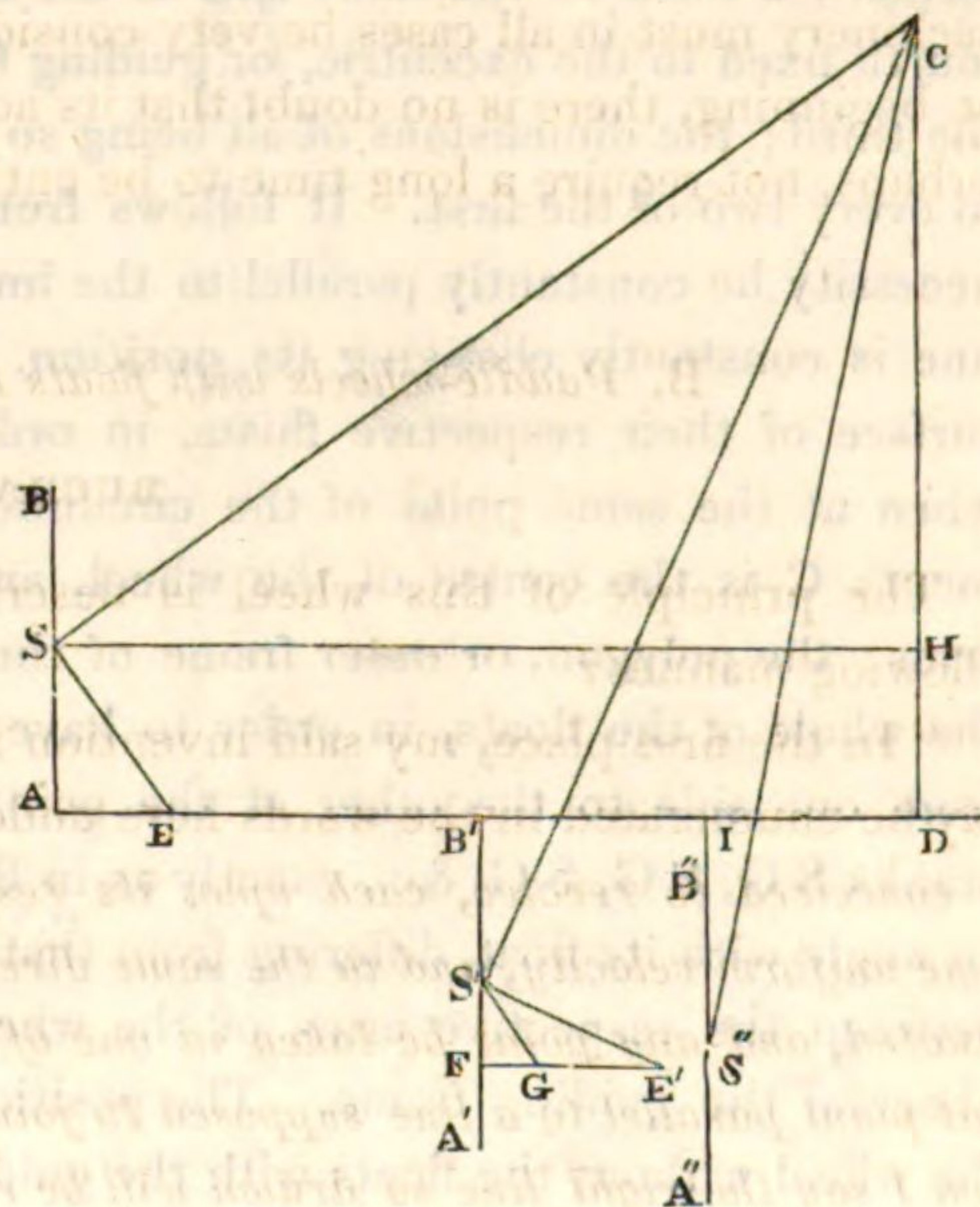
Fig. 1, Plate III., is a diagram of Buchanan's wheel, which has been drawn of the same

dimensions and with the same number of floats as those of the 'Phoenix' and 'Salamander.' From the centre of a framing similar to that of the common wheel, and called by the patentee the *pitch-wheel*, rrr are the radii or arms; SSS spindles, working in bearings in the circumference of the pitch-wheel; each spindle is attached to a float, represented in the diagram by the straight line AB , which is divided into two equal parts by the spindle, one end of which passes through the pitch-wheel, and is furnished with a lever or crank SG . The extremity G of this lever is bent at right angles to SG , and works in a bearing on the circumference of a flat wheel or frame GGG , called by the patentee the *connection wheel*, which turns on an axle fixed to the ship's side, excentrically with respect to the pitch-wheel, its centre being situated at a different point. This axle is made sufficiently large to admit of the shaft passing through it. The crank SG is equal in length, and constantly parallel to the line that joins the two centres.

The float, being fixed to the crank, must evidently remain constantly parallel to a fixed straight line during the whole of each revolution of the wheel, nor can any alteration in the proportions of the parts cause it to change its position; indeed it would be impossible to make the wheel revolve, if any other length or position were given to the crank or lever SG . This essential property of Buchanan's wheel is amply sufficient to distinguish it from another, known by the name of Morgan's wheel. We mention this because some persons have confounded these two wheels together from ignorance of their respective properties, although they are widely different both in principle and construction.

Fig. 2, Plate III., shows the path of one of the floats of the wheel represented in fig. 1, under the same circumstances as those of the 'Phoenix' in fig. 2, Plate I. Fig. 3 is the enlarged node. Figs. 4 and 5 correspond with figs. 4 and 5, Plate I., which relate to the trial of the 'Salamander.' In both these cases the floats back water, or move forward in the same direction as the vessel, but most considerably at the deep immersion. We will not, however, investigate the action of the wheel under such circumstances, but suppose the velocity of the wheel to be such that the floats, at their immersion and emersion, shall move in a vertical direction.

In the adjoining figure let CS represent the radius, AB the float, and S the spindle, at the instant the lower edge of the float enters the water, CD a vertical line, AD the water line, and SH a horizontal line, passing through the spindle S and intersecting the line CD at the point H . Let $CS = R$, $CH = a$, $AB = f$, and the breadth of the float $= b$; let ϕ = the inclination of the radius at any given instant, and its inclination at the instant its lower edge enters the water, or the angle SCD , $= \alpha$; also let SE , perpendicular to the radius CS , $=$ the *circumferential velocity* of the float, $= V$, and v = the velocity of the vessel.



In order that the preceding condition may be satisfied, it is evident that there must exist the following relation between v and V ,

$v = V \cos. a$;
for v must be equal to AE , which is equal to $SE \cos. SEA$; but the angle $SEA =$ the angle $SCD = a$; therefore $v = V \cos. a$; and ρ , the radius of the *rolling circle*, $= R \cos. a = a$.

The *effective velocity* of the float in any given position is $V \cos. \phi - v$. For let $A'B'$ be the given position of the float, the angle $S'CD$ being equal to ϕ , and let $S'E'$, perpendicular to the radius CS' , $= V$, and the portion $E'G$ of the horizontal line $E'F$, which intersects $A'B'$ at the point F , $= v$; the straight line $S'G$ will represent the motion of the float both in direction and velocity, and FG , which is perpendicular to its surface, will be equal to its *effective velocity*. Now we have $E'F = S'E' \cos. S'E'F = V \cos. \phi$, and $E'G = v$, therefore *effect. vel.* $= FG = E'F - E'G = V \cos. \phi - v$, or, substituting for V and v their respective values, viz., $V = \frac{\pi R n}{30}$ and $v = V \cos. a = \frac{\pi R n}{30} \cos. a = \frac{\pi a n}{30}$,

$$\text{Effect vel.} = \frac{\pi n}{30} [R \cos. \phi - a].^1$$

OLDHAM'S PADDLE-WHEEL.

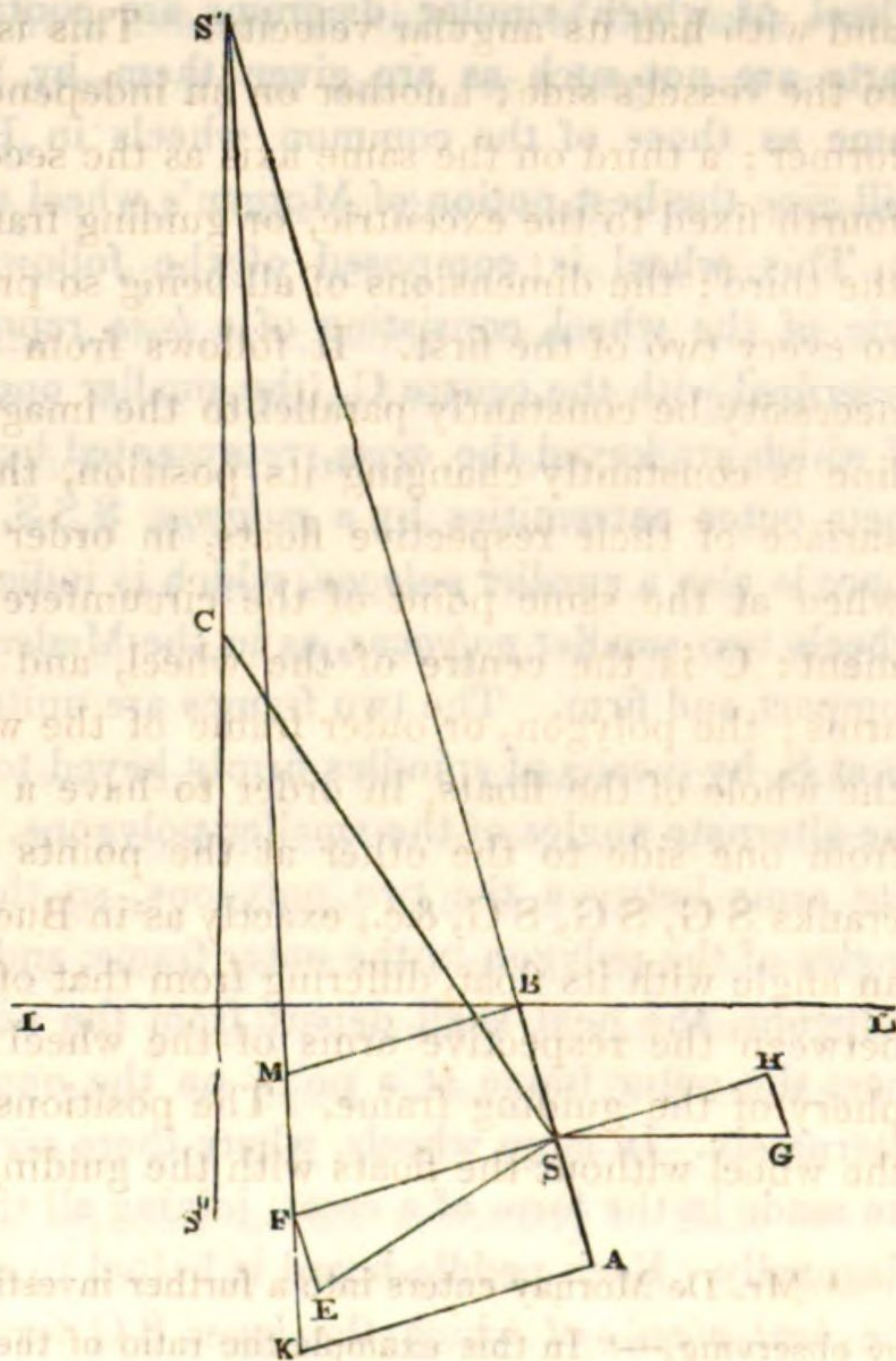
The principle of this wheel will be perfectly understood by conceiving the axis of the excentric in Buchanan's to revolve round the main shaft in the same direction as the latter, and with half its angular velocity. This is effected by fixing a spur-wheel on the shaft close to the vessel's side; another on an independent axis fixed to the vessel's side, working in the former; a third on the same axis as the second, and fixed to it, but of a different size; and a fourth fixed to the excentric, or guiding frame, concentrically with the main shaft, working in the third; the dimensions of all being so proportioned that the last shall make one revolution to every two of the first. It follows from this, that as each paddle-crank or lever must of necessity be constantly parallel to the imaginary line which joins the two centres, and as this line is constantly changing its position, the cranks must be set at different angles with the surface of their respective floats, in order that the latter may all have the same inclination when at the same point of the circumference. Fig. 1, Plate IV., will explain this arrangement: C is the centre of the wheel, and E that of the guiding frame, rrr the radii or arms; the polygon, or outer frame of the wheel, FFF , is made sufficiently large to include the whole of the floats, in order to have a bearing for cross-stays, which traverse the wheel from one side to the other at the points FFF , &c.; SSS , &c., are the spindles with the cranks SG , SG , SG , &c., exactly as in Buchanan's wheel, except that each crank, SG , makes an angle with its float, differing from that of the next on either side by half the angle included between the respective arms of the wheel; ggg , &c. are the arms, and GGG , the periphery of the guiding frame. The positions of the paddle-cranks are easily found by drawing the wheel without the floats with the guiding frame in any arbitrary position (in the figure its

¹ Mr. De Mornay enters into a further investigation of the properties of this invention, and concludes by observing,—“In this example the ratio of the effective to the total power is only 0.443, which shows that the principle of vertical paddles is in this case fallacious.”—ED.

centre is immediately over the shaft, but any other position would do as well); the line CE being given, all the cranks must be parallel to it, and the floats radiate from the highest point of the circumference which passes through the spindles; each float being then fixed to its crank, will evidently radiate from the same point during the whole of every revolution of the wheel, and its inclination will consequently always be half that of the radius.

The action of this wheel is theoretically very good, the pressure on the floats being nearly uniform throughout the stroke; but the great friction, liability to get out of order, and other difficulties attending its construction, have hitherto overbalanced its theoretical advantages. The wheel represented in the next figure is of the same dimensions as those in the preceding plates, and the same speed and number of revolutions in each of the figures 2 and 4, as in the corresponding figures in the other plates. In comparing the nodes, figs. 3 and 5, with those of the other wheels shown in Plates I. II. III., the superiority of Oldham's wheels is manifest: the float strikes the water, on entering, less violently than that of the common wheel, having at that moment less *effective velocity*, and there is throughout less loss from *oblique action*, from its inclination being always less: the whole immersed surface of the float is always effective, which gives it another advantage over the divided float of Field's wheel; and the radius of the *rolling circle* is not limited, as with Buchanan's, which causes a great proportion of the power to be spent simply in turning the wheels.

To investigate the action of the floats, let LL be the water line, C the centre of the wheel, $S'S''$ its vertical diameter, CS one of the radii, AB the float, and S the spindle. Let $R =$ the radius CS ; $f = AS$, the half-depth of the float. Produce AB until it meet the vertical diameter at the point S' , and let $\delta =$ the angle $SS'S''$ contained between the surface of the float and the vertical. Let SE , perpendicular to $CS =$ the *circumferential velocity* of the spindle $= V$, and the horizontal line $SG =$ the velocity of the vessel $= v$. Through the point S draw a straight line FH perpendicular to AB , and from the points E and G draw EF and GH perpendicular to FH , and meeting it at the points F and H ; the difference between FS and SH will be the *effective velocity* of the spindle. Now, the angle ESF being equal to the angle $SS'S''$ or δ , we have $FS = V \cos. \delta$, and, because the angle $GSH = \delta$, we have also $SH = v \cos. \delta$; therefore, the *effective velocity* of the spindle $= (V - v) \cos. \delta$, which is always positive, for the speed of the vessel is always less than the *circumferential velocity* of the spindle. Through the points S' and F draw a straight line $S'K$, and from any point A of the line AB draw another straight line AK parallel to SF , and inter-



secting the former at the point K; $AK - SH$ will be the *effective velocity* of the point A: for since the float always radiates from S' , we may consider that point as the centre of revolution, in which case SF would represent the *circumferential velocity* of the spindle, and consequently AK that of the point A. Now, if we combine this with the horizontal velocity SG , and resolve the resultant into two others, one perpendicular and the other parallel to AB , the former, which is the *effective velocity* of the given point, will be found to be equal to $AK - SH$. Let z = the distance of the given point from the spindle, taken positively towards the lower edge of the float, and negatively towards its upper edge.

In principle, Oldham's wheel is very superior, but in a practical point of view so exceptionable, that unless some much better method of carrying the principle into execution be devised, it can never be made to succeed. It is, however, perfectly useless to attempt the improvement of this wheel, since the one we are about to describe possesses the same theoretical advantages in a still higher degree, and is as simple in construction as can reasonably be expected.

MORGAN'S PADDLE-WHEEL.

This wheel being of some importance on account of the extent to which it has already been employed and its decided superiority over all others that have hitherto been used, and having been very much misrepresented, we feel it necessary to be explicit in showing its peculiarities of principle and construction. Fig. 1, Plate V., is a diagram of Morgan's wheel, intended merely to explain its principle, and as a comparison with the other kinds of wheel of which similar diagrams are contained in the plates. The proportions of the parts are not such as are given them by the manufacturer, Mr. Wm. Morgan, being the same as those of the common wheels in Plate I. The elevations of the Medea's wheel will give the best notion of Morgan's wheel as made at present.

This wheel is composed of the following parts: an iron frame-work, forming each side of the wheel, consisting of a *boss*, represented in fig. 1 by the larger of the two circles described with the centre C, (the smaller one is the section of the *shaft*,) in the circumference of which are keyed the *arms*, represented by the radial lines rr , &c., and these are united at their outer extremities by a *polygon*, SSS , made of round iron for the sake of lightness; there is also a smaller *polygon*, which is indicated in the figure but without letters, and in large wheels two smaller *polygons*, as in the Medea's wheel; these serve to render the frames more compact and firm. The two frames are united together at the angles of the outer polygons, as at S, by means of spindles firmly keyed to the frames, and by *diagonal stays* of iron from the alternate angles of the smaller polygons, in small wheels, to points situated on the opposite arms between the two polygons, so that if one *diagonal stay* departs from one of the angles of the polygon in the outer frame, and joins the inner frame at a point between the two polygons, the next shall depart from the next angle of the polygon in the inner frame, and meet the outer frame at a point on the opposite arm between the two polygons, and so on alternately. In large wheels, where there are three polygons in each frame, the *diagonal stays* are made in the form of a cross, joining all the angles of the four smaller polygons two by two diagonally. Each paddle-board is bolted to a kind of frame of iron, called the *stem* (originally the *bent stem*), of which the lever SG forms a part, and which is furnished with two steel *bushes*, made to turn on steel collars fixed on the spindle, which are accurately turned and

polished. The *stem-lever* S G is fixed at any angle with the surface of the float which may be most convenient, that, as well as its length, having very little influence on the motion of the float, and none at all, within certain limits, on its inclination as it enters and leaves the water. In order to leave room in the interior of the wheel for the machinery which is to guide the floats, the shaft is only fixed to the *boss* of the inner frame, and does not pass through as in other wheels: this does not, however, much affect the solidity of the wheel, for the *diagonal stays* make it nearly as strong, if not equally so, with no more weight of metal than there would be in the piece of shaft which is dispensed with; in practice, at least, no deficiency of strength has been experienced on that account. The guiding machinery consists of a *crank* whose axis is fixed to the spring beam in a line with the main shaft, and passes through the centre of the outer *boss* of the wheel; the *crank head* is shown at E, abaft the axis of the wheel, and slightly elevated above it; on this revolves a *collar*, round the circumference of which are *pin-jointed* the *guide rods*, *h, h*, &c., each of which is pin-jointed at its other end to the extremity, G, of one of the *stem-levers*. One of the *guide rods*, *g*, is an exception, being keyed, and not pin-jointed, as the others are, to the *revolving collar*, and is called the *driving rod*, because by its means the *collar* is driven, or made to revolve at the same time as the wheel. It acts upon one of the floats in the same manner as the other *guide rods*.

The object of this combination is evidently to regulate the inclination of the floats by alternately increasing and diminishing the distance between the spindles and the excentric centre E, to obtain which centre is the sole intention of the crank; but as it was found impracticable to make all the *guide rods* as well as the driving rod radiate from that centre, the *revolving collar* was added in order to obtain excentric centres for the rest of the *guide rods*, and this collar ought to be as small as it can conveniently be made, for a large one would cause a variation in the action of the different floats.

There is a great advantage in the mode of hanging the floats in this wheel, which cannot be applied to Buchanan's or Oldham's, viz., that the spindles, being fixed in the frames of the wheel, contribute greatly to its solidity, and the *stem-levers*, being situated in the centre of the floats, to which they are firmly fixed, are much more efficient instruments to guide the floats than the cranks in the two other wheels, which, besides being on one side and at a considerable distance from the floats, have very weak bases in consequence of their axes having to turn in bearings in the framing of the wheel, and are thus very liable to ring, which must be very injurious to the action of the wheel, as all the floats are guided by one single piece.

It is astonishing that Morgan's wheel should ever have been for a moment confounded with Buchanan's, the principle and construction of the two differing from each other so widely as they do. The difference of principle has been already pointed out, and in construction they differ materially: in Buchanan's wheel the *pin-jointed guide rods* are entirely wanting, and the *revolving collar* is enlarged to the size of the principal framing of the wheel; the levers by means of which the floats are feathered *must* be equal in length, in Buchanan's wheel, to the distance between the centre of the wheel and that of the excentric, while in Morgan's they *never* are: in Buchanan's wheel the spindles *revolve* uniformly in their bearings, for which reason the cranks must be outside the wheel, as otherwise they could not pass, while in Morgan's the floats *vibrate* on their spindles, which motion allows of the *stem-levers* being situated in the interior of the wheel.

Oldham's wheel is still more distinct from Morgan's in construction, by reason of the gear for causing the excentric axis to revolve; it resembles it, however, much more in effect, as the floats are constantly changing their inclination, but the fixed law, that this must always be exactly half that of the radius, allows of no deviation, while in Morgan's wheel there exists no fixed relation between the inclination of the float and that of the radius.

We shall presently have to describe another wheel, which has been declared to be the same as Morgan's, which it resembles very much; namely, that invented by M. Cavé, engineer, at Paris. In this, all the *guide rods* are *pin-jointed*, the *revolving collar* being driven by a different instrument from the *driving rod, g*, in Morgan's wheel, which is not so uniform in its action.

The superiority of Morgan's over the common wheel is shown in a striking manner by the 14th and 21st experiments in Mr. Barlow's Table, page 9. They were both made with Her Majesty's steamer 'Firebrand,' the former with the old wheels, and a pair of 70-horse engines, the latter with Morgan's wheels and a pair of sixties, both light. In the former case her speed was 10.15 miles, and in the latter 10.55, being improved by four-tenths of a mile with one-seventh less power. The common wheels had each 14 floats of 18 square feet area, and Morgan's only 9 floats of less than 13 square feet area, which proves that the latter kind of wheel does not *require* so much float as *is given* to the former to produce an equal effect. The economy of fuel arising from the use of Morgan's wheels has also been proved.

Captain Austin, formerly commander of the 'Medea,' expressed an opinion that Morgan's wheels were, as *sea-propellers, most valuable and perfect*.

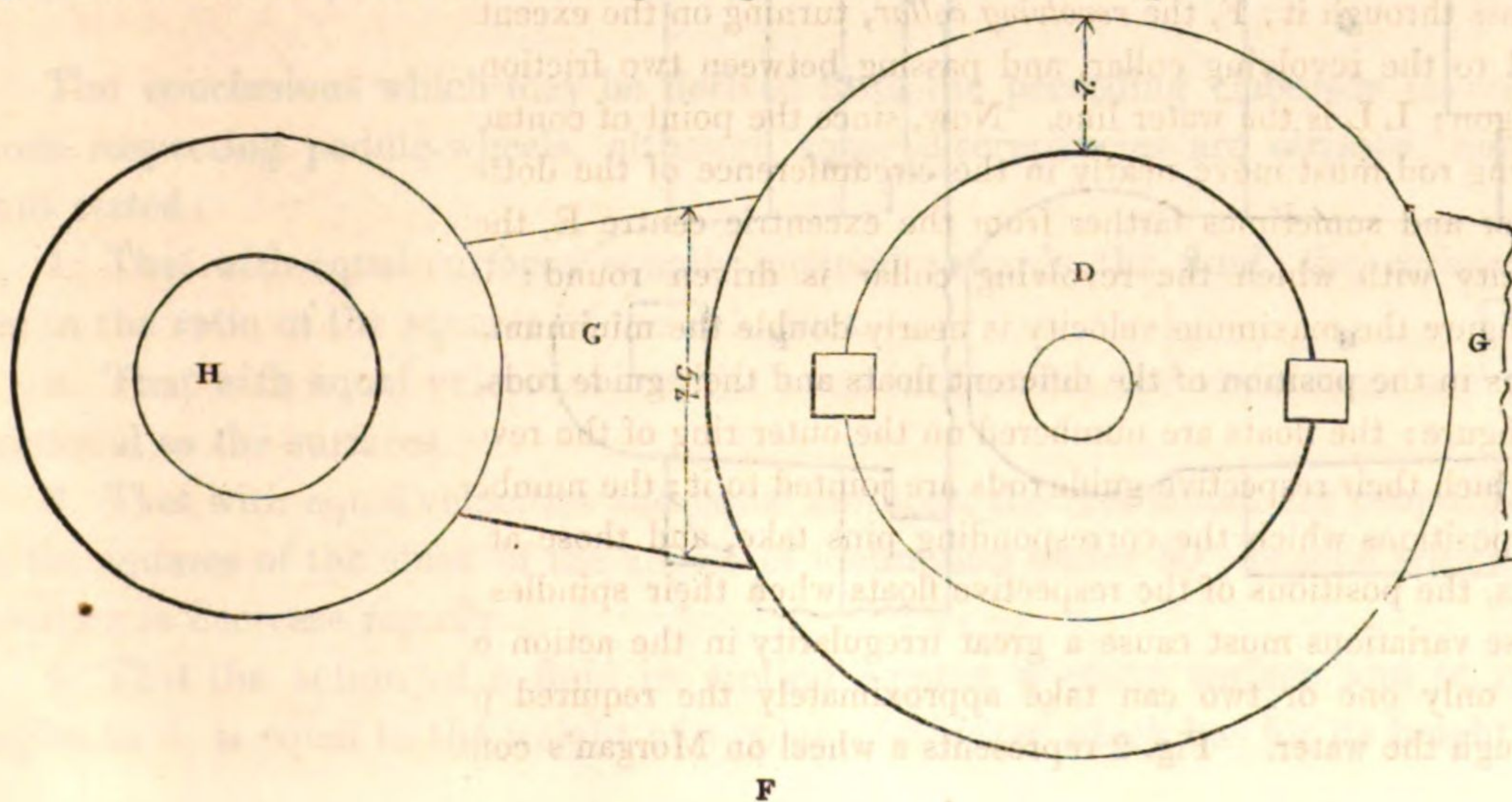
CAVÉ'S PADDLE-WHEEL.

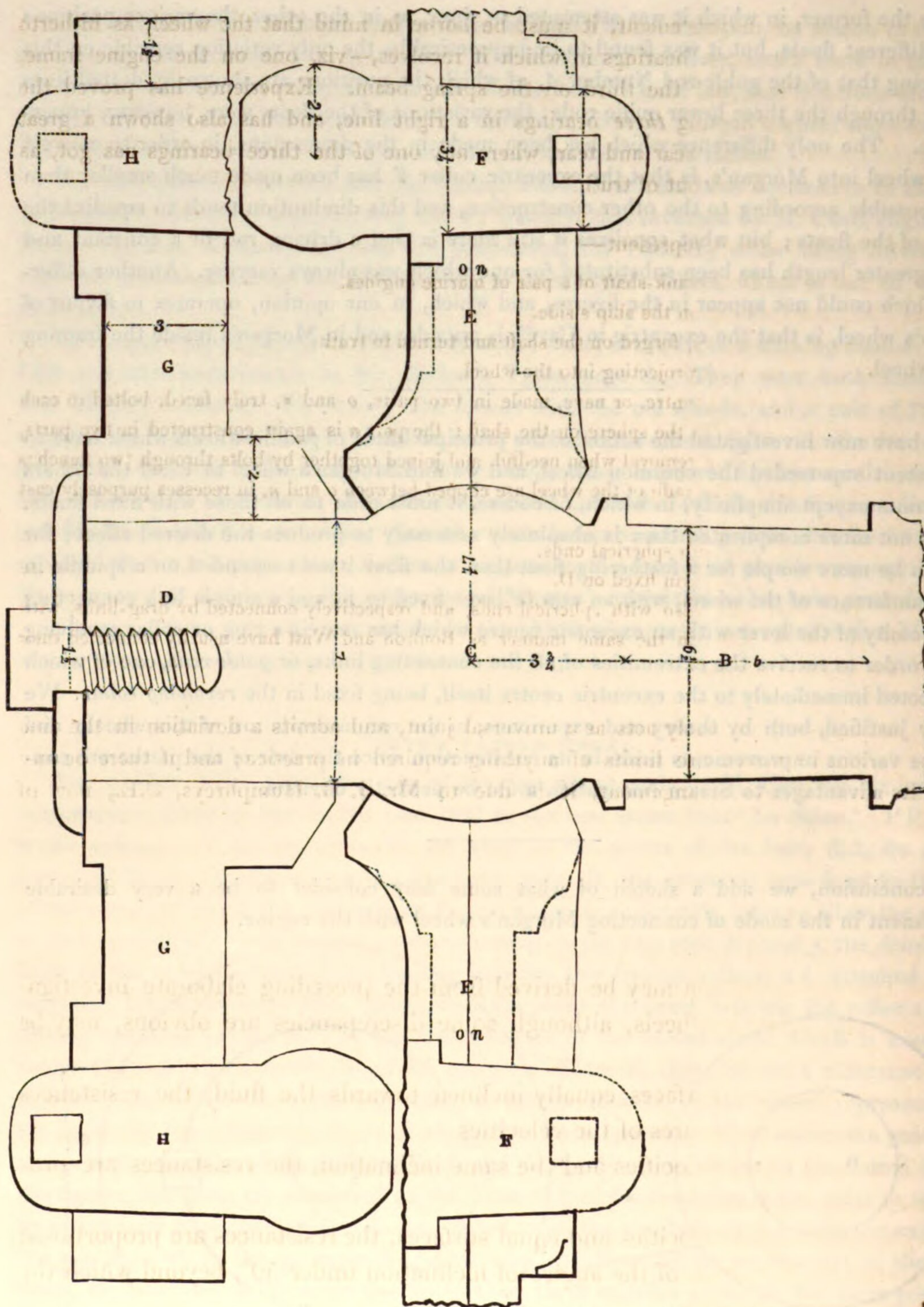
Fig. 1, Plate VIII., is an elevation of the first wheel made by M. Cavé on his improved construction, fitted by him in the year 1827 to the iron steam boat 'La Seine.' PPP, &c. is the *polygon*; rr, &c. the *arms*; C, the *shaft* in the centre of the *boss*; AA, &c. are the *floats*; DD, &c. the *stems*; hh, &c. the *guide rods*; B, the *excentric axis* fixed to the side of the vessel, of which the centre is at E, and which is sufficiently large to allow the shaft C to pass through it; F, the *revolving collar*, turning on the excentric B; and g, the *driving rod*, fixed to the revolving collar, and passing between two friction rollers, kk, attached to the polygon; LL is the water line. Now, since the point of contact between the roller and the driving rod must move nearly in the circumference of the dotted circle, which is sometimes nearer and sometimes farther from the excentric centre E, there results a difference in the velocity with which the revolving collar is driven round: in the wheel represented in the figure the maximum velocity is nearly double the minimum. This causes the great variations in the position of the different floats and their guide rods, shown by the dotted lines in the figure: the floats are numbered on the outer ring of the revolving collar, close to the pins by which their respective guide rods are jointed to it; the numbers on the excentric axis show the positions which the corresponding pins take, and those at the extremities of the lower floats, the positions of the respective floats when their spindles arrive at the same positions. These variations must cause a great irregularity in the action of the floats, and it is evident that only one or two can take approximately the required positions during their motion through the water. Fig. 2 represents a wheel on Morgan's construction of the same dimen-

sions as the former, in which it was attempted to show, as in the other, the various positions of the different floats, but it was found to be impracticable, the only variation sensible on this scale being that of the guide rod Number 4, of which the positions are shown by dotted lines passing through the three lower guide rods: the variations of the floats were, however, imperceptible. The only difference which has been made in the dimensions, in order to convert Cavé's wheel into Morgan's, is that the excentric collar F has been made much smaller than it was possible according to the other construction, and this diminution tends to equalize the motion of the floats; but what equalizes it still more is that a driving rod of a constant and always greater length has been substituted for one which was always varying. Another difference, which could not appear in the figures, and which, in our opinion, operates in favour of Morgan's wheel, is that the excentric in Cavé's is outside, and in Morgan's inside the framing of the wheel.

We have now investigated the action of the principal kinds of paddle-wheels which have to some extent superseded the common wheel, and we find Morgan's wheel to excel the others in all points except simplicity, in which, of course, it must cede to all those with fixed floats, but it is not more complicated than is absolutely necessary to produce the desired effect; for what can be more simple for a feathering float than the float itself suspended on a spindle in the circumference of the wheel, with an arm or lever fixed to it, and a simple link connecting the extremity of the lever with an excentric centre which has merely a ring or collar revolving on it in order to receive the extremities of all the connecting links, or *guide rods*, one of which is connected immediately to the excentric centre itself, being fixed in the *revolving collar*. We are fully justified, both by theory and experience, in the recommendation of this wheel; and when the various improvements made in its construction since the date of the patent are considered, its advantages to Steam Navigation must be perfectly obvious.

In conclusion, we add a sketch of what some may consider to be a very desirable improvement in the mode of connecting Morgan's wheel with the engine.





To appreciate the improvement, it must be borne in mind that the wheel, as hitherto constructed, has *three* main bearings in which it revolves,—viz. one on the engine frame, one on the ship's side, and the third on the spring beam. Experience has proved the great difficulty of maintaining *three* bearings in a right line, and has also shown a great increase in friction, and in wear and tear, where any one of the three bearings has got, as workmen express it, 'much out of truth.'

The preceding diagrams represent—

- A. A part of the outer crank-shaft of a pair of marine engines.
- B. The journal bearing on the ship's side.
- C. A portion of a sphere, forged on the shaft and turned to truth.
- D. The end of the shaft projecting into the wheel.
- E E. Part of the wheel centre, or nave, made in two parts, *o* and *n*, truly faced, bolted to each other, and turned to fit the sphere on the shaft: the part *n* is again constructed in two parts, for the convenience of removal when needful, and joined together by bolts through two flanches across the nave. The radii of the wheel are clipped between *o* and *n*, in recesses purposely cast for them.
- F F. Two crank-pins with spherical ends.
- G G. A double-driving arm fixed on D.
- H H. Two crank-pins, also with spherical ends, and respectively connected by drag-links, with the pins in the nave, in the same manner as Boulton and Watt have usually connected their marine engine cranks.

This arrangement obviously acts as a universal joint, and admits a deviation in the line of bearings much beyond the limits of anything required in practice; and if there be any merit belonging to this arrangement, it is due to Mr. J. B. Humphreys, C.E., now of Rio Janeiro.—ED.

The conclusions which may be derived from the preceding elaborate investigations respecting paddle-wheels, although some discrepancies are obvious, may be thus stated:

1. That with equal surfaces equally inclined towards the fluid, the resistances are in the ratio of the squares of the velocities.
2. That with equal velocities and the same inclination, the resistances are proportional to the surfaces.
3. That with equal velocities and equal surfaces, the resistances are proportional to the squares of the sines of the angles of inclination under 50° , beyond which the resistances decrease rapidly.
4. That the action of a fluid in motion against a plane surface and at right angles to it, is equal to the weight of a column of water which has for its height the

height which a body would fall to communicate the velocity, and of which the base is the surface acted upon.

5. The maximum velocity being given, the maximum effect will be produced by a paddle-wheel when it will move through the water with a relative velocity of one-third of the maximum.

Experiments upon the shock and resistances of fluids against planes and solids have been made by many authorities, from the period when Sir Isaac Newton first promulgated the theory of molecular action, as illustrated by experiment, down to the more elaborate experiments of the French Academy, still further amplified by experiments of the English Naval Architectural Society, conducted by Beaufoy.

These general laws were founded upon the motion of a fluid vein of water which, if left to itself, would acquire a uniform velocity according to the laws of gravity; but which, if opposed by any plane surface or solid, would be arrested in its course, and cause its particles, from their extreme mobility, to diverge from the centre towards the border of the plane or solid, and escape beyond them. The result would be a rise or pressure of the water against the surface of the plane and a certain amount of resistance, which resistance has been found to be in the ratio of the square of the velocity, as before stated; and experiment proves that when an isolated vein of water impinges against a plane surface, smaller or even equal to its section, the height due to the shock is the same as the height due to the velocity of the fluid vein: the intensity of the shock, however, depends considerably on the freedom which the particles have of deviating from the surface towards the exterior of the plane. The experiments of Bossut showed that the effective pressure upon the plane was only equal to $\frac{2}{3}$ rds of the area of the fluid vein; but if the surface present a greater area than the vein, the velocity lost being greatly augmented, the resistance will be greater in consequence. The general conclusion from Bossut and other experimenters is, that the shock of a fluid vein against an obstacle is proportional to the height due to the velocity of the vein or square of that velocity; but to produce the greatest effect from the shock or percussion of a fluid vein, the area of the plane should exceed the diameter of the vein six or eight times, while the experiments of Bossut and Bidone¹ give twice the diameter or four times the area. The resistance, however, was found to be greatly increased by Morosi, who in 1812 found that by adding a small raised border round the edge of a plane or disc, the effect of a jet was nearly doubled. These experiments were subsequently repeated and amplified by Bidone, who found the mean effect of 180 experiments to increase in the ratio of 1.177, or $1\frac{3}{4}$ times greater with the borders round the edge of the disc than without.

¹ Expériences sur la Percussion des Veines d'Eau, par George Bidone: Turin, 1836.

These experiments were further repeated and corroborated to a greater extent by Colonel Du Chemin,¹ who, in an essay on the properties of fluids, communicated some valuable experiments upon the deviations and velocities and shocks of the fluid particles of water when in motion against a solid at rest or in motion, and from which experiments he deduces formulæ applicable to the different cases of resistance. The author attributes all the resistances which solids meet with from the inertia, viscosity, and friction of the fluid, to the same causes as his predecessors, but differs from them in respect to their relations. He agrees partly with Venturi and with Coulomb as to the expression of the resistances being represented by two terms, viz. by the squares of the velocities, and by the velocity simply,—the latter of which he thinks should be neglected entirely beyond a certain velocity. The term *square of the velocity*, which is generally applied to the inertia and friction of the fluid, ought to be applied to the viscosity; and in repeating these experiments in oil, which is of greater viscosity, the term proportional to the *simple velocity* is seventeen times greater in oil than in water, while the term square of the velocity is the same in the two fluids, which shows that the term simple velocity depends on the viscosity of the fluid, while the other is entirely independent; in short, friction, according to Du Chemin, is proportional to the square of the velocity. The experiments upon the deviation of the fluid vein were performed, in 1829, with an instrument similar to those of Bossut and Dubuat. The instrument consisted of a plate of iron 0·422 metres diameter, a square of 0·3 metres of a side, and of a rectangle 0·3 metres in height by 0·2 metres in width. These plates were pierced with sixteen holes of 0·003 metres, of which twelve were numbered from one upwards. The plates were successively exposed to the current under different immersions and heads, and the flow of the water through the different holes accurately observed. The observations were then carefully tabulated and traced on diagrams; and the results were, that when the circular disc was exposed to the current, the fluid particles were distributed in radii from the centre to the circumference; and when the square disc was used, the water separated in four bands or triangles into currents in diagonal direction, the same as with the rectangular disc. The discs were also moved against the current with similar effect, thus establishing the usually received theory of the resistance being the same whether the plane receives the shock of the current or moves against it: similar experiments were repeated with oblique surfaces. It was proved also, that the height to which a fluid is raised against the surface of a plane, when it remains fixed or moves, is the same whatever the breadth of the plane.

¹ Recherches Expérimentales sur les Lois de la Résistances des Fluides, par M. le Col. Du Chemin.
—Extract du Mémorial de l'Artillerie.

As regards the other resistances which a plane disc experiences in moving the water, the resistance is principally due to the exterior pressure, to which it is proportioned for all bodies wherever their length and diameter are in a constant ratio.

The experiments upon the vortices or curves assumed by the water at the posterior surfaces of planes and cubes in motion are corroborated by those of Avanzini.¹

The most important experiments, however, in relation to the motions of paddle-wheels, viz. those by Morosi,—proving that if a float of a given area and resistance round a border be added round the edge, the resistance is double,—have been partly confirmed by the author of this Paper.

We may here add a brief account of the PATENT TRAPEZIUM FLOAT-WHEELS.²

As Mr. EWBANK, of New York, has devoted much time to this subject, and is the author of a valuable work on 'Hydraulic Machinery,' his observations are entitled to attention.

The facts developed by his experiments may be briefly stated; they are as follow:

1st. That with equal areas and equal dip, triangular blades may be rendered twice as effective as ordinary rectangular ones; and this, too, while the propelling surface of the smaller number of floats was only one-half that of the greater.

2nd. That as the propelling power of a paddle is greater at its greater or outer extremity, and diminishes to nothing at the surface, so its face should enlarge with the dip, and be nothing above—in imitation of the tails of fishes, the wings of birds, &c.

3rd. That the fewer the number of paddles on a wheel, the better, provided one be always kept in full play; and,

4th. That it would be more advantageous to point or fork them as proposed, to evade the jar of their striking the surface.

Mr. Ewbank refers to the experiments made on H. M. steamer 'African,' in the year 1841, but which he had not been able to find, although similar experiments on two other vessels were published in the 'Civil Engineer's Journal' for January 1840.

In the year 1831,* my attention was attracted to this subject during the

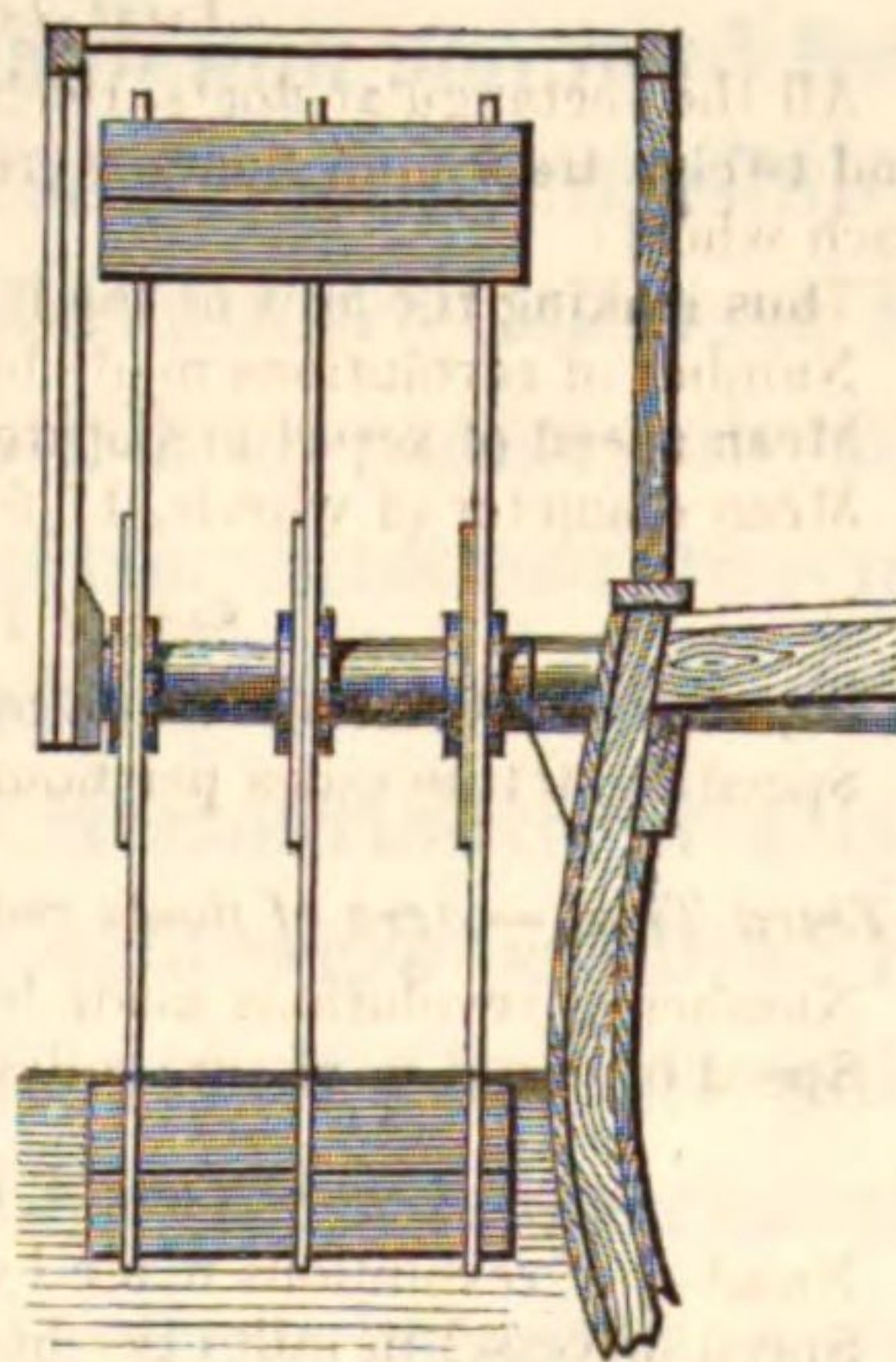


Fig. 1.—Ordinary System.

investigations undertaken for the purpose of ascertaining the laws of the friction and resistances of solids in motion in fluids such as air and water,—when, on causing discs or plates of metal to rotate round a fixed axle by means of weights descending through given spaces and times, it was found that when a certain portion (one-fourth) of a rectangular disc or fan was intercepted from the interior part of the rectangle, so as to approximate to the form of a duck's-foot, the resistance, whether through air or water, was the same—or, in other words, the resistance with *three triangular* or duck-footed floats was as great as previously with four rectangular floats. This apparent paradox was, however, accounted for on the principle of the interior or detrimental portion of the rectangular float being removed.

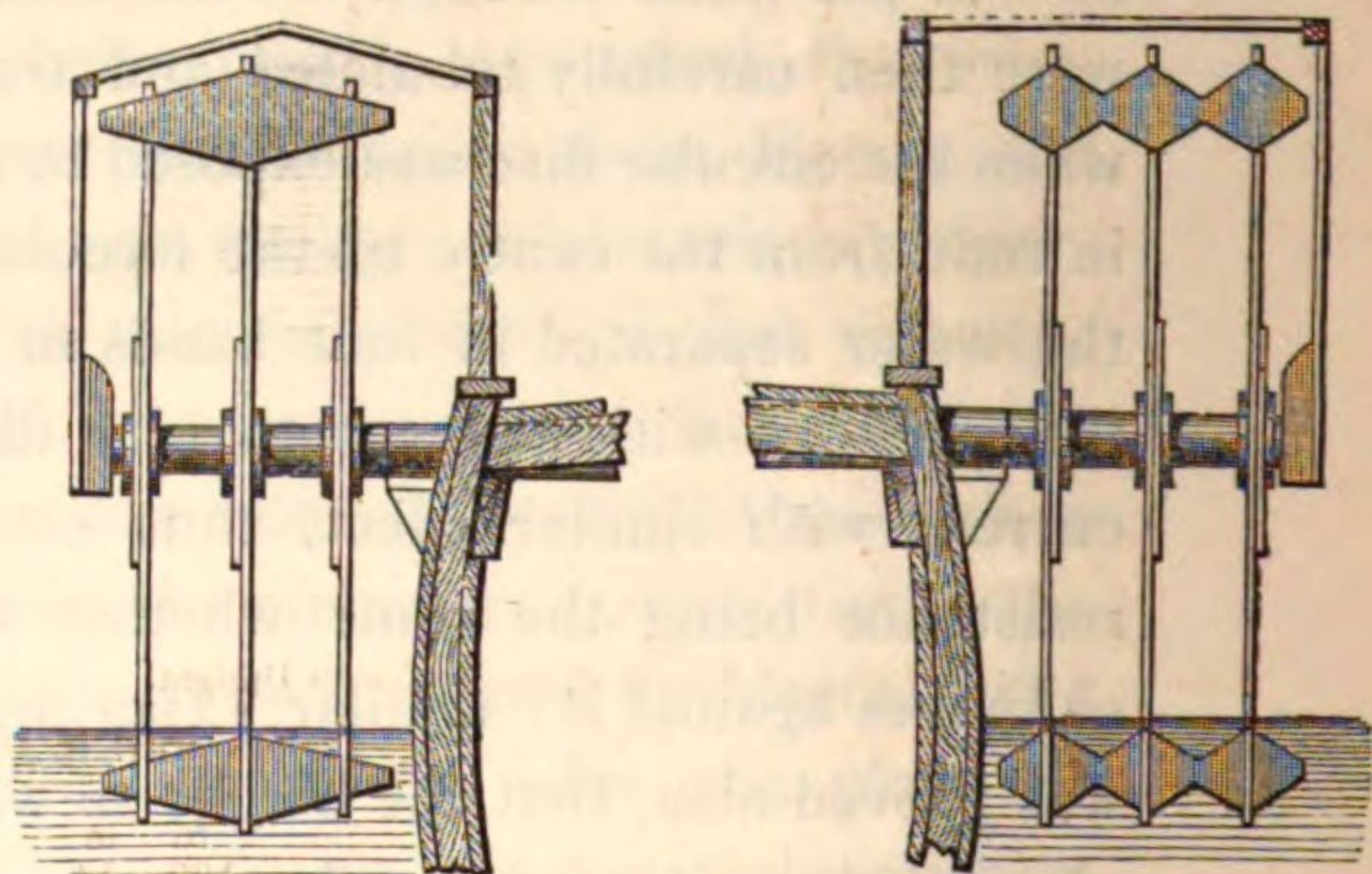


Fig. 2.—Modifications of Ordinary System.

A series of experiments on two other vessels was again made in the years

* See 'Philosophical Transactions' for 1831.

¹ Istituto nazionale d'Italia, tom. i. part i.

² From the 'Civil Engineer and Architect's Journal.'

1839, 1840, and 1841, by applying different-shaped floats to paddle-wheels of different diameters and widths, and on steam vessels of different powers of from 6 to 90 horses.

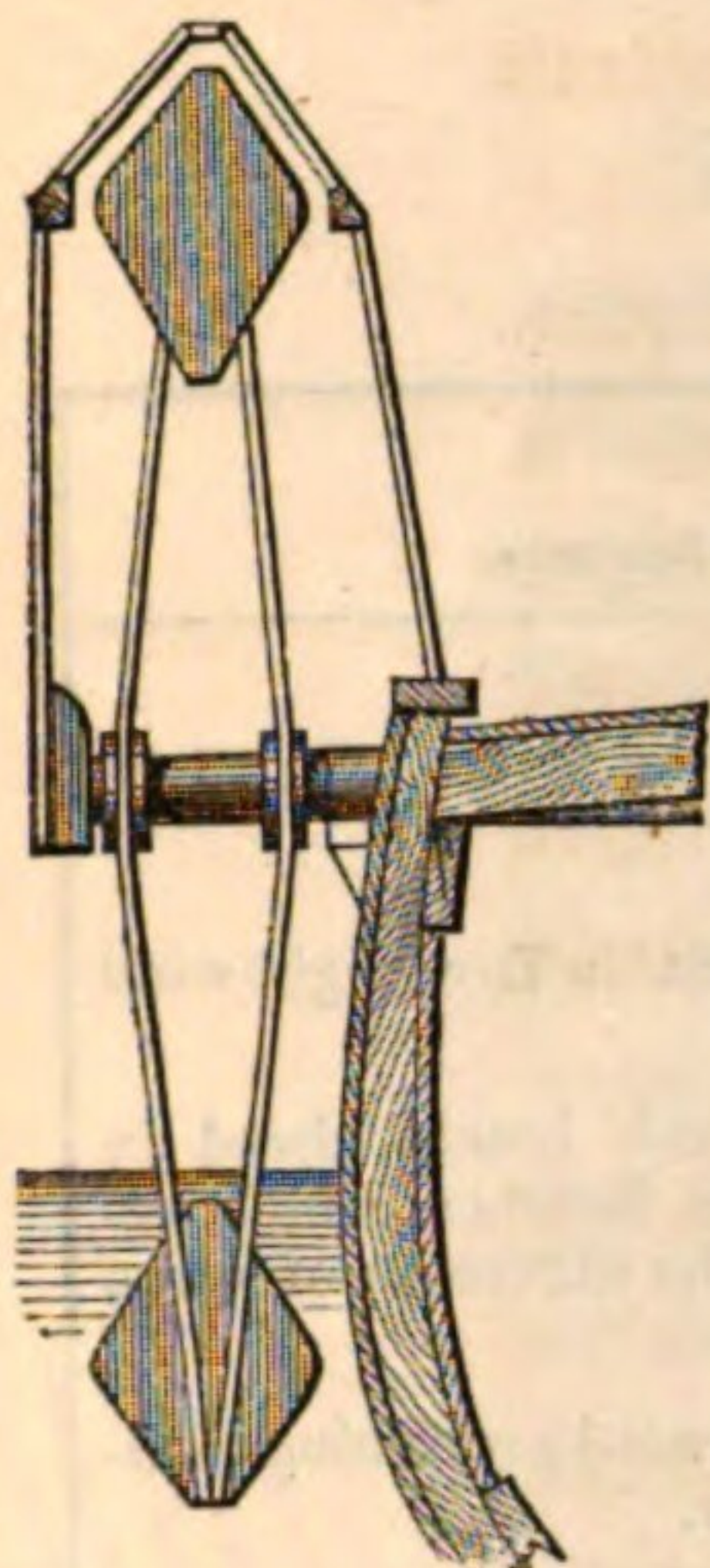


Fig. 3.—Improved Trapezium System.

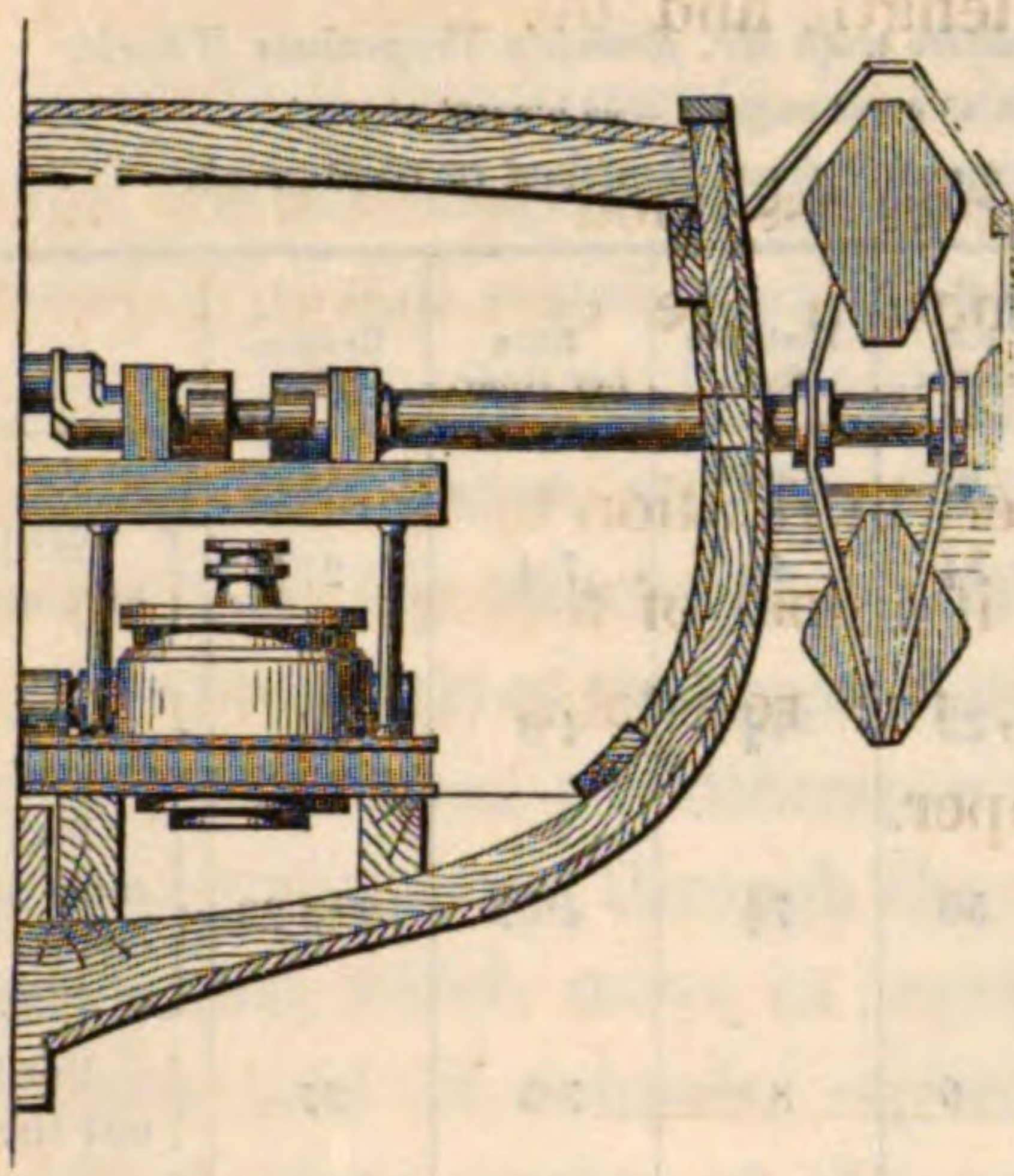


Fig. 4.—Improved Trapezium System, with wheels of smaller diameter and greater velocity.

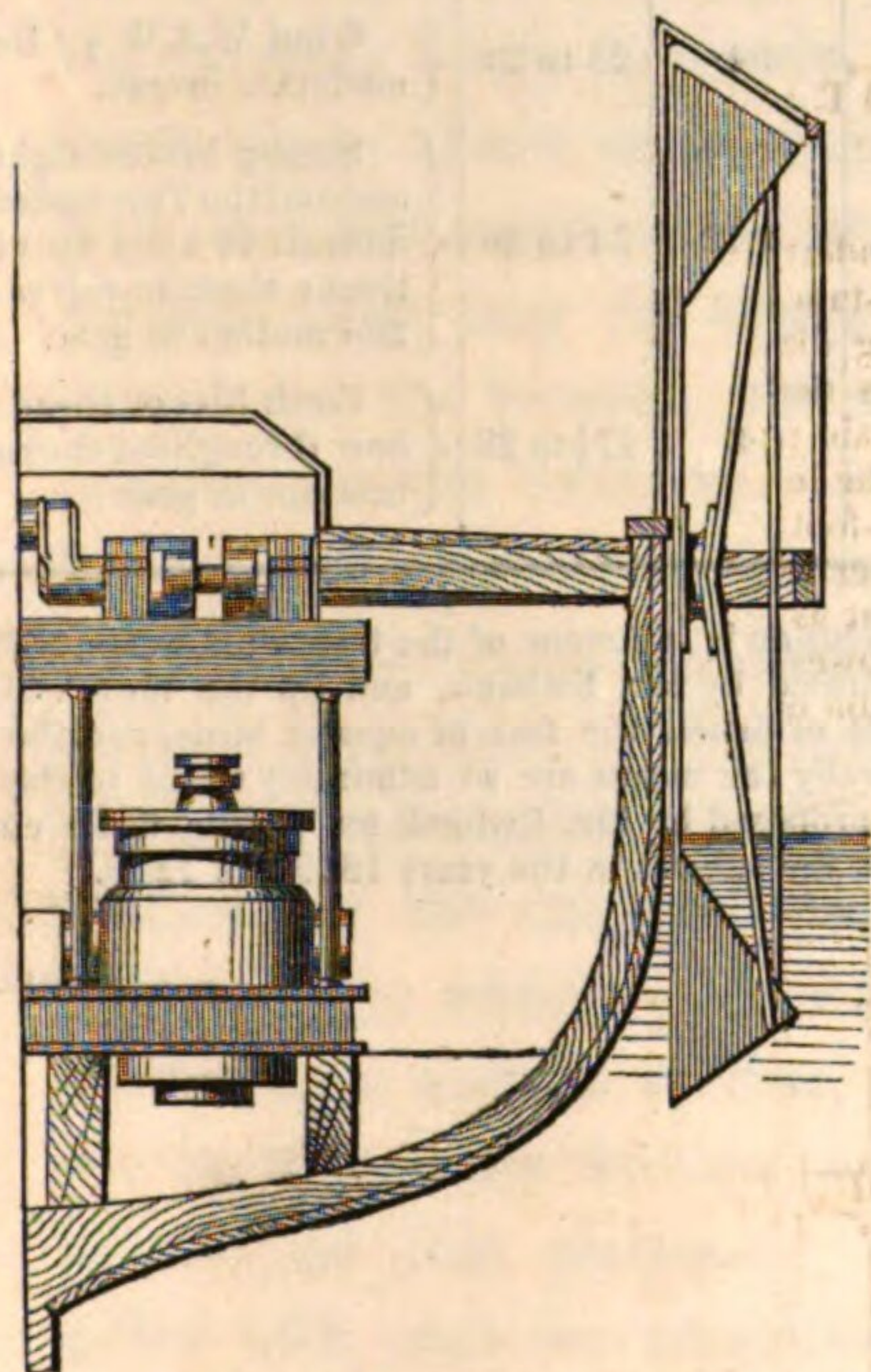


Fig. 5.—Improved Triangular System when the vessel is Upright.

The following were the particulars of the 'African' when tried in 1837, previous to her being tried in 1841:—

	ft.	in.
Length between perpendiculars	109	11
Extreme breadth	24	10
Mean draught	9	4½
Depth	10	0

Nominal power of engines (by Maudslays and Field) 45 horses, or 90 horses together.

Number of strokes made by the engines per minute, 29 to 30.

Barometer gauge, 24 to 26¼ inches.

Area of immersed midship section, 150 square feet.

Mean diameter of the paddle-wheels, 14.7.

Area of the immersed rectangular floats, on the cycloidal or Galloway system, twelve in number, 7 feet in length, and 1 foot 9 inches in breadth; thus presenting an area of from 57 to 60 square feet, being a ratio of 1 foot of float to 2⅙ midship section.

When the above trial was made, at the measured mile in Long Reach, her average speed of six trials each way was 9.174 statute miles per hour with her rectangular floats. Subsequently, she was employed for towing and other purposes, and had never undergone any other repairs than in her engines, and had never been in dry dock: her bottom was consequently foul, and covered with green weeds, when tried with the trapezium floats in 1841.

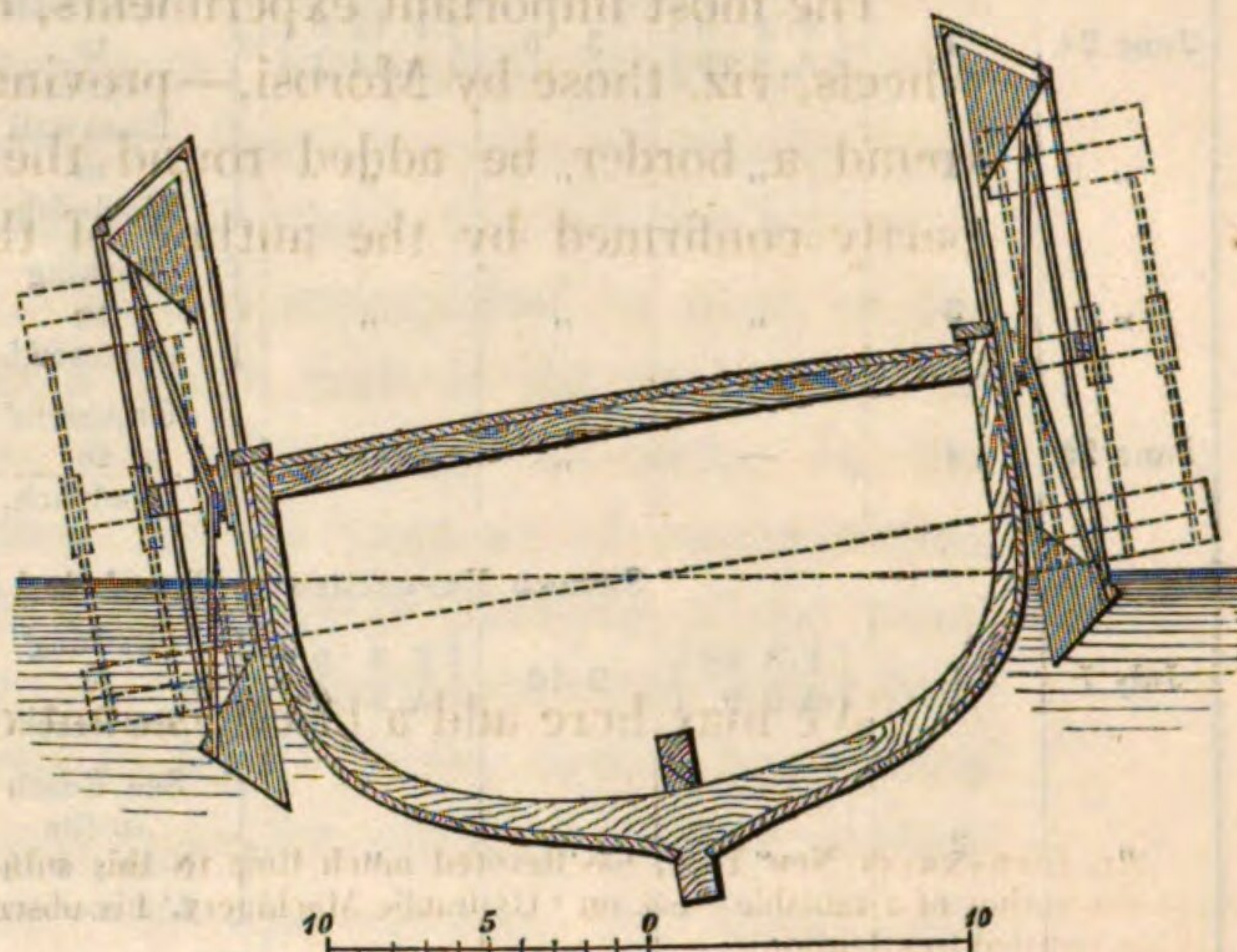


Fig. 6.—Improved Triangular System when the vessel is Inclined.

Experiments on H. M. Steamer 'African,' with Trapezium Floats.
First Trial, April 14, 1841.

All the rectangular floats, twelve in number on each wheel, were removed, and twelve trapezium floats were fixed to the interior and middle rings of each wheel:

Thus making the area of the immersed floats, 34 square feet.

Number of revolutions made by engines, 23½ per minute.

Mean speed of vessel in statute miles, 9.1.

Mean diameter of wheels, 17 feet.

Second Trial, April 21, 1841.

Number of revolutions made by engines per minute, 23.

Speed in statute miles per hour (weather very windy), 8¾.

Third Trial.—Area of floats reduced one foot each, and reefed-up 4 inches.

Number of revolutions made by engines per minute, 25½.

Speed of vessel in statute miles per hour 9.022.

Fourth Trial, June 8, 1841.

Number of revolutions made by engines per minute, 25.

Speed of vessel in miles per hour (weather windy), 8.8.

Fifth Trial, June 9, 1841.—Immersed float surface reduced to 22 square feet area, and reefed-up 11 inches; or reducing the diameter of the wheel 22 inches.

Number of revolutions made by engines per minute, 27½.

Speed of vessel in statute miles per hour 9.124.

The barometer stood at from 25 to 26 inches.

Which result was nearly equal to her former speed (viz. 9.174) in 1837, with rectangular floats of more than double the immersed area of the trapezium floats.

ON PADDLE-WHEELS.

Experiments with Towing, as per the accompanying Table.

In June 1841, the 'African' towed the 'Numa' transport, of 323 tons, at the rate of $5\frac{1}{2}$ statute miles per hour.

In July following she towed H.M. steam frigate 'Dee,' of 704 tons, and 200

horse-power, 5 statute miles per hour,—which was only 1·6 mile per hour less than her greatest speed when propelled by her own engines, or 6·6 miles per hour.

Woolwich Yard, }
July 9, 1841. }

'African,' Steam-Tug; Trials of her Towing Qualities with Mr. Rennie's Trapezium Wheels.

(Tonnage, 323 tons new measurement. Power, 2×45 horse engines = 90 horses' power.)

FIRST EXPERIMENT—Towed the 'Numa' Transport from Deptford to Greenwich.

Date.	No. of Experiment.	Draft of Water of Tug.	Dip.	Draft of Vessel Towed.	Where tried.	Duration of Experiment.	Distance Run.	Rate per Hour.	Revolutions.	Remarks.
		ft. in.	ft. in.	ft. in.		h. m.	knots.			
June 24	1	{ F. 9 0 A. 9 10 }	3 0	{ F. 12 8 A. 14 1 }	{ Woolwich to Deptford.	0 34	$4\frac{1}{2}$	7·4	27 $\frac{1}{2}$	{ Without the Tow; two patent logs used.
"	2	"	"	"	{ Blackwall to Woolwich.	0 23	$1\frac{5}{8}$	4·8	24	{ The 'Numa' in Tow; light wind ahead.
"	3	"	"	"	{ Barking to Gravesend.	1 50	$7\frac{1}{2}$	4·09	19 to 23	{ Pretty fresh breeze ahead in some of the Reaches, which accounts for the difference of speed of engines.
June 25	4	—	"	—	{ Gravesend to Woolwich.	1 6	8	7·3	27	{ But little wind; returning without the Tow.

SECOND EXPERIMENT—Towed the 'Dee' Steam Frigate from Woolwich to Sheerness.

July 7	1	{ F. 8 9 $\frac{1}{2}$ A. 9 9 }	2 10	{ F. 8 9 A. 8 0 }	{ Barking to Sea Reach.	2 25	$11\frac{3}{10}$	4·4	23 to 24	{ Wind W.S.W.; 'Dee' in Tow; moderate breeze.
"	2	"	"	"	{ Sea Reach to the Nore; with 2nd motion.	2 0	$8\frac{85}{100}$	4·42	34 to 38	{ Strong breeze right aft, which assisted the Tow materially; steam difficult to keep up at 38 revolutions; throttle-valves half open; 2nd motion in gear.
July 8	3	"	"	—	{ Lower part of Sea Reach to Barking.	3 15	$22\frac{1}{10}$	6·8	27 $\frac{1}{4}$ to 28	{ Fresh breeze ahead and on the bow throughout the run; 2nd motion not in gear.

The official report only differs by half a mile between the towing powers of the 'African' with her rectangular floats in 1837, and the trapezium floats in 1841; so that considering that the area of the trapezium floats was merely adapted to propelling the 'African' simply as regarded speed, these trials could hardly be taken as the criterion of their powers as applied to towing, when the areas should have been increased expressly for that purpose. But, comparing the whole of the experiments when tried in still water under the most favourable circumstances, and when tried in the 'African' under the unfavourable circumstances of foul bottom and difference of the powers of the

engines, the conclusion is in favour of the trapezium floats. The truth of the principle is confirmed by Mr. Ewbank, and by the laws which govern the forms of the tails of fishes, the feet of aquatic birds, and the wings of birds and insects, whereby the means are so admirably suited to the ends; and the triangular form proposed by Mr. Ewbank for paddle-floats entirely confirms the view taken of the subject in the years 1839 and 1840.

GEORGE RENNIE.

The preceding experiments had been previously tried in models by means of weights and various shaped floats, attached to the extremities of the arms of paddle-wheels moving in still water, and confirmed on a larger scale in a steamer of 50 tons expressly fitted with wheels for the purpose, and then in the West India Import Dock, also in still water, so that there could be no doubt of the accuracy of the experiments, and the conclusions derived therefrom; the results proving, *cæteris paribus*, the advantages of the trapezium or triangular floats over the rectangular ones, — arising no doubt from the difference of velocity with which the interior and exterior edges or circles move through the water. This is exemplified in most of the natural propellers which move in segments of a circle, such as the webbed feet of aquatic birds, and of animals, reptiles, fish, &c. The wings of birds, on the contrary, have their angles at the extremities, for the purpose of compensating the difference of velocity between the exterior and interior portions of the wing, the breadth being inversely as their velocities: hence birds of rapid flight have their wings more acute than birds of slower motion. Fish, again, have their tails and fins more acute or forked in proportion to the rapidity of their motion: among these may be classed the sword-fish, the histiophorus, the tunny, the corypheus, the bonetta, and all Mediterranean fish. The mackerel, the herring, the salmon, on the contrary, — where the form of the tail is less acute and varies from the triangle to the trapezium, such as the cod-fish, the bream, the electric eel with its spiral-like ventral fin, and flat fish in general, — are slow in proportion to the shape of their propellers. The turtle and seal may be classed with the latter. The progressive instruments of the aquatic insect tribe are variously illustrated in the motions of the coleopterous insects; among which may be classed the dytiscus or water-beetle, which is admirably adapted for swimming, having a body resembling a boat, with a smooth surface, to enable it to glide easily through the water, and with the least possible friction, when impelled by its legs or oars, which are peculiarly formed for that purpose. The notonecta or water-boatman is also powerfully gifted with oars for progression. The cephalopoda use their tentacula projecting them behind as oars.

The *aquatic larvæ* perform their motions by abrupt strokes with their legs against the surface of the water, and move wonderfully quick in all directions over its surface. The dragon-fly, by the sudden ejection of a fluid from a cavity behind, is impelled in a contrary direction to its natural formation, similar to the course of a rocket. The Infusoria tribe of insects, such as the hydra rotifera vibris, &c., perform their motions by alternations or rotations. The medusæ (or sea-blubber)

progress by the pulsatory motions they give to the mushroom-like cup which opens and shuts alternately.

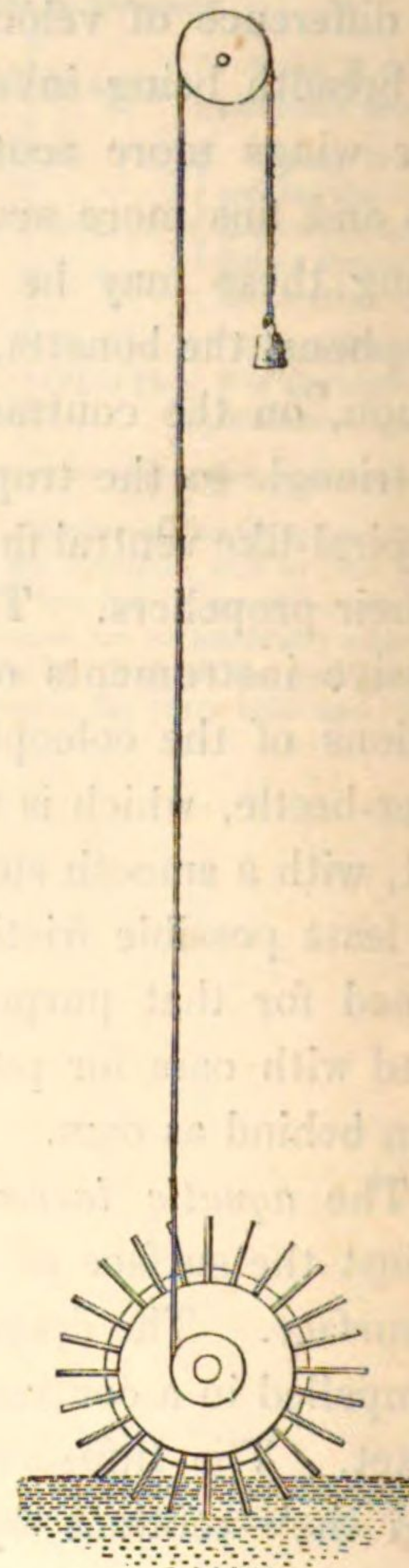
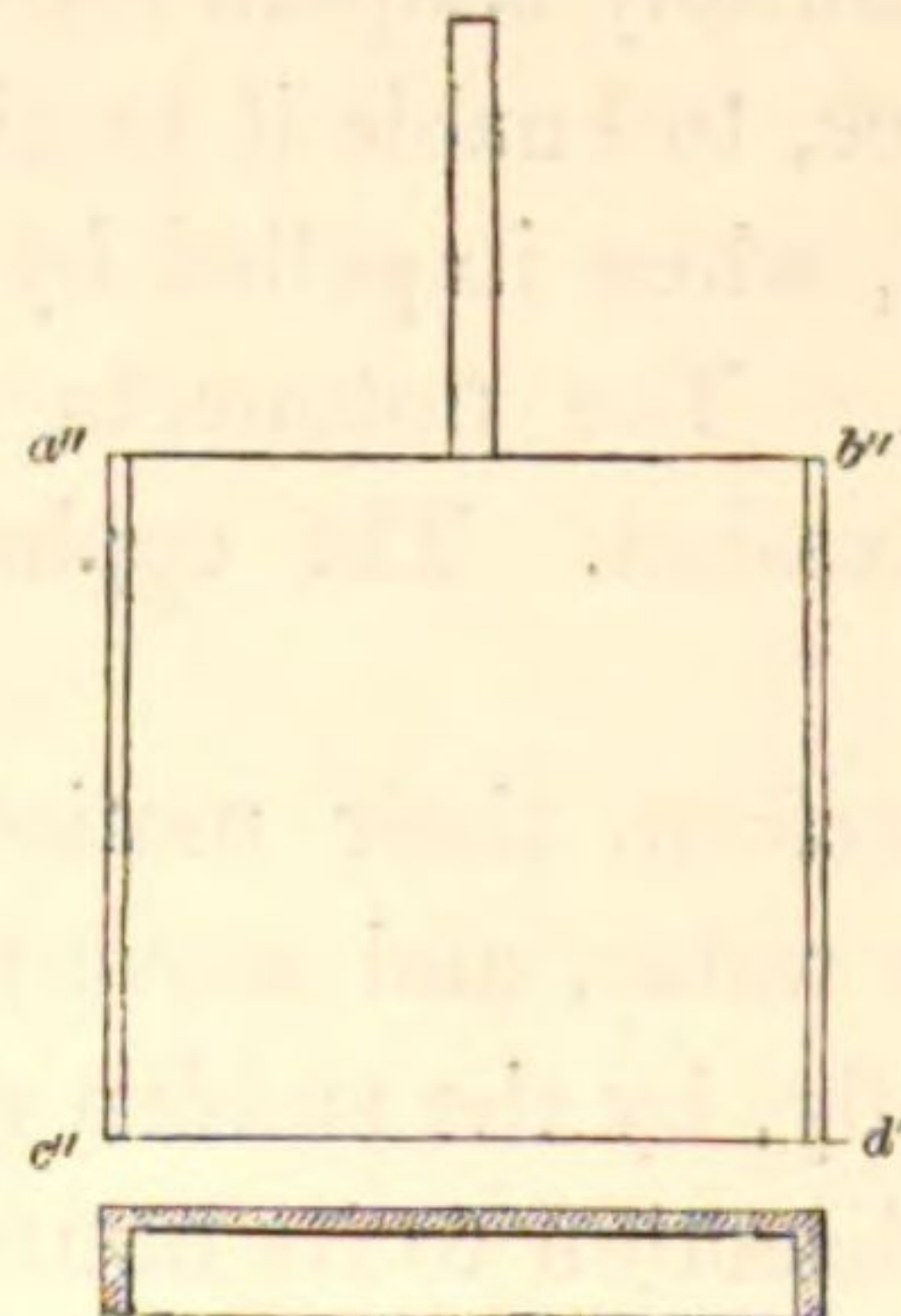
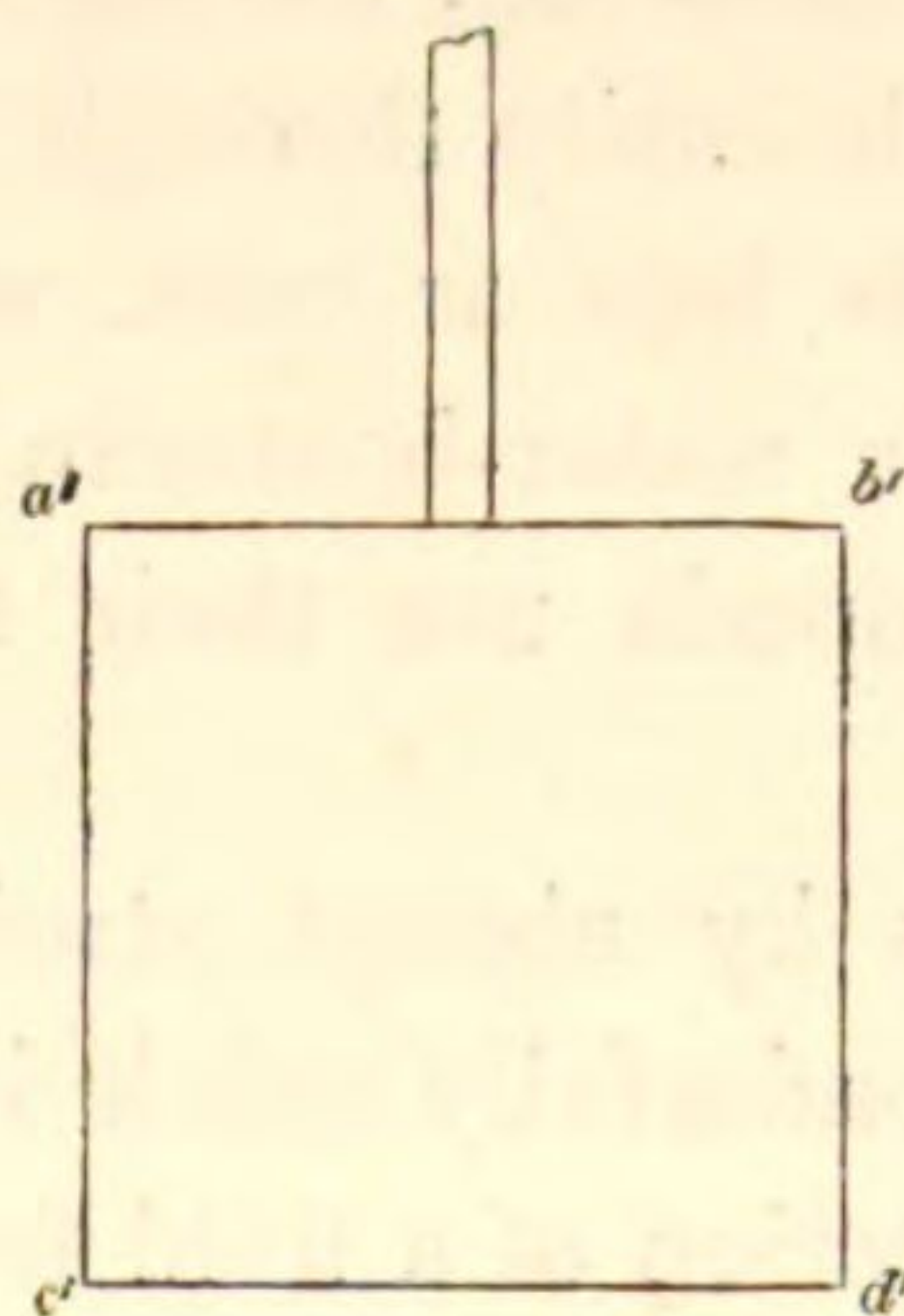
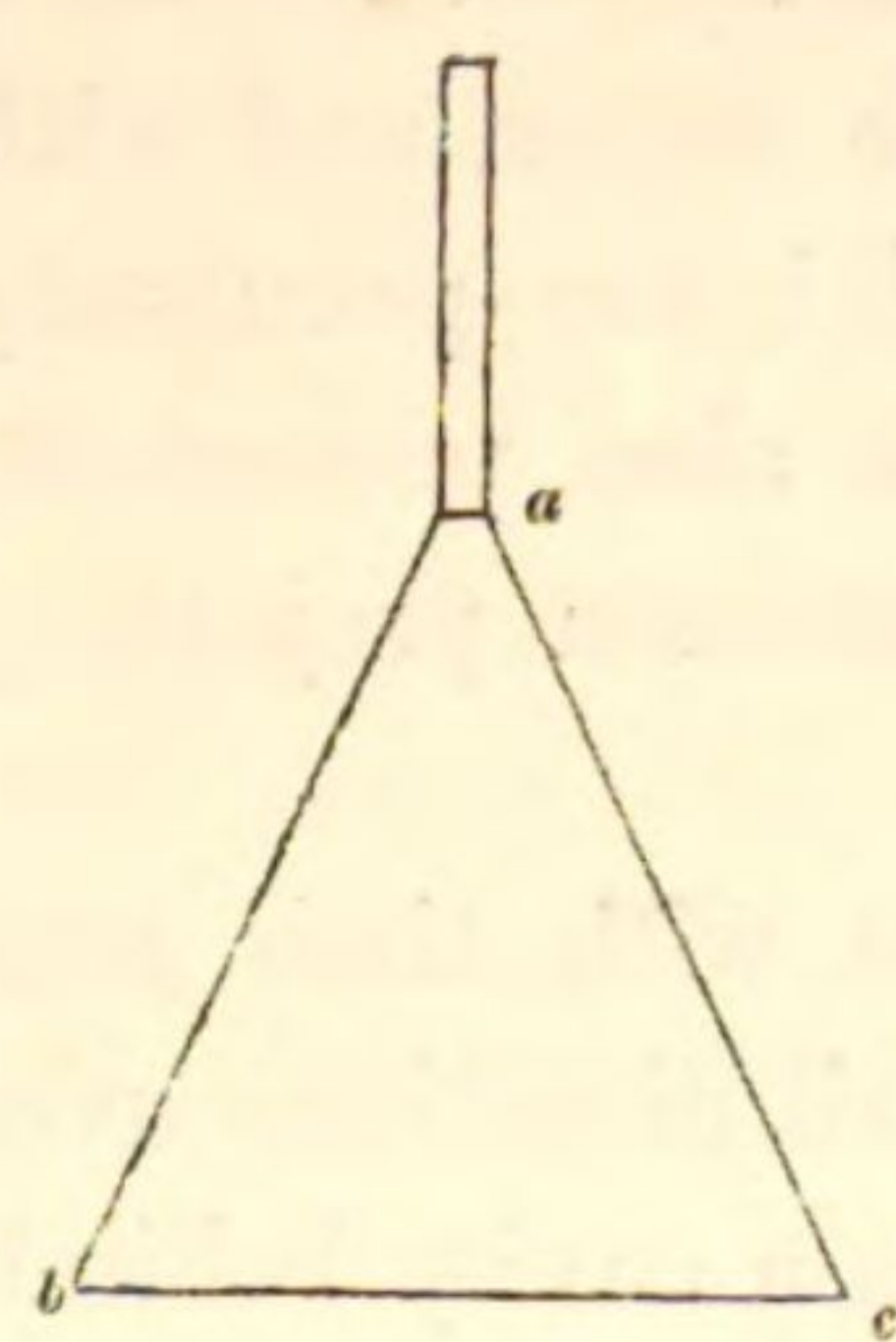
The preceding examples are merely quoted to show how infinite are the ways of Creation.

Result of Experiments made with Floats of various Forms working in a Trough of Water by means of Weights falling from a Height of 24 feet 5 inches, July 27th, 1852.

The Resistance of each Float is indicated by the time, in seconds, in which the several Weights descend.

Height.	Weight.	Time, in seconds.	Time, in seconds.	Time, in seconds.
ft. in.	lbs.			
24 5	1			
	2	80	82	
	3	51½	58	62
	4	43	48½	48½
	5	35½	42½	42
	6	30	37½	38

Form of Floats.



As a further illustration of Mr. RENNIE's researches, the following Paper on the PROPULSION of STEAM VESSELS, by Mr. EWBANK, of New York, is extracted from the 'Annual Exposé,'—a work especially designed "to promote the progress of science and the useful arts," and a portion of which is devoted to such communications as point out new channels of thought, and tend to enlarge the area of invention.

ON THE PROPULSION OF STEAMERS.

BY MR. EWBANK, OF NEW YORK.

THE subjoined synopsis of original experiments recently made and illustrated by various types of Nature's propellers, point out, as has been conceded, elements of marine progression that have hitherto been frequently overlooked by Nautical Engineers. The facts developed are respectfully submitted to Congress, as elucidations of a subject deserving the special attention of the General Government.

Oceanic Steamers are too essential links of the system of cheap and free portage—domestic and international—to be allowed to pursue undisturbed their present average passages. To this great and growing element of modern civilization and of universal brotherhood they have yet much to contribute. The Ferry-Boats of Nations,—they must make their runs from continent to continent, so as to rival, both in regularity and speed, the lines of land locomotives which they severally serve to connect.

The proposition may be a startling one, that the further men advance in science, the longer become their strides, and the easier they are taken : yet so it is. Locomotive navigation may be cited as an example : surprisingly rapid as has been its growth, it is yet in its infancy. Born in our day, its greatest feats are yet to be performed. By gallantly dashing through the palings which some savans had imprudently reared before them, Oceanic Steamers have already read the learned a lesson about laying out boundaries for science, and hedging in enclosures for art, which will not be soon forgotten.

It is with artificial as with natural motive mechanism : an intimate relationship exists between the members, reaching to the minutest and remotest. If one be out of order, all feel the effect. A lame leg makes its owner halt ; an inflamed finger, toe, or tooth, deranges more or less the whole body : just so with a steamer whose instruments of progression are defective in figure, out of place, or disproportionate ; she too limps, though neither the infirmity nor the seat of it may

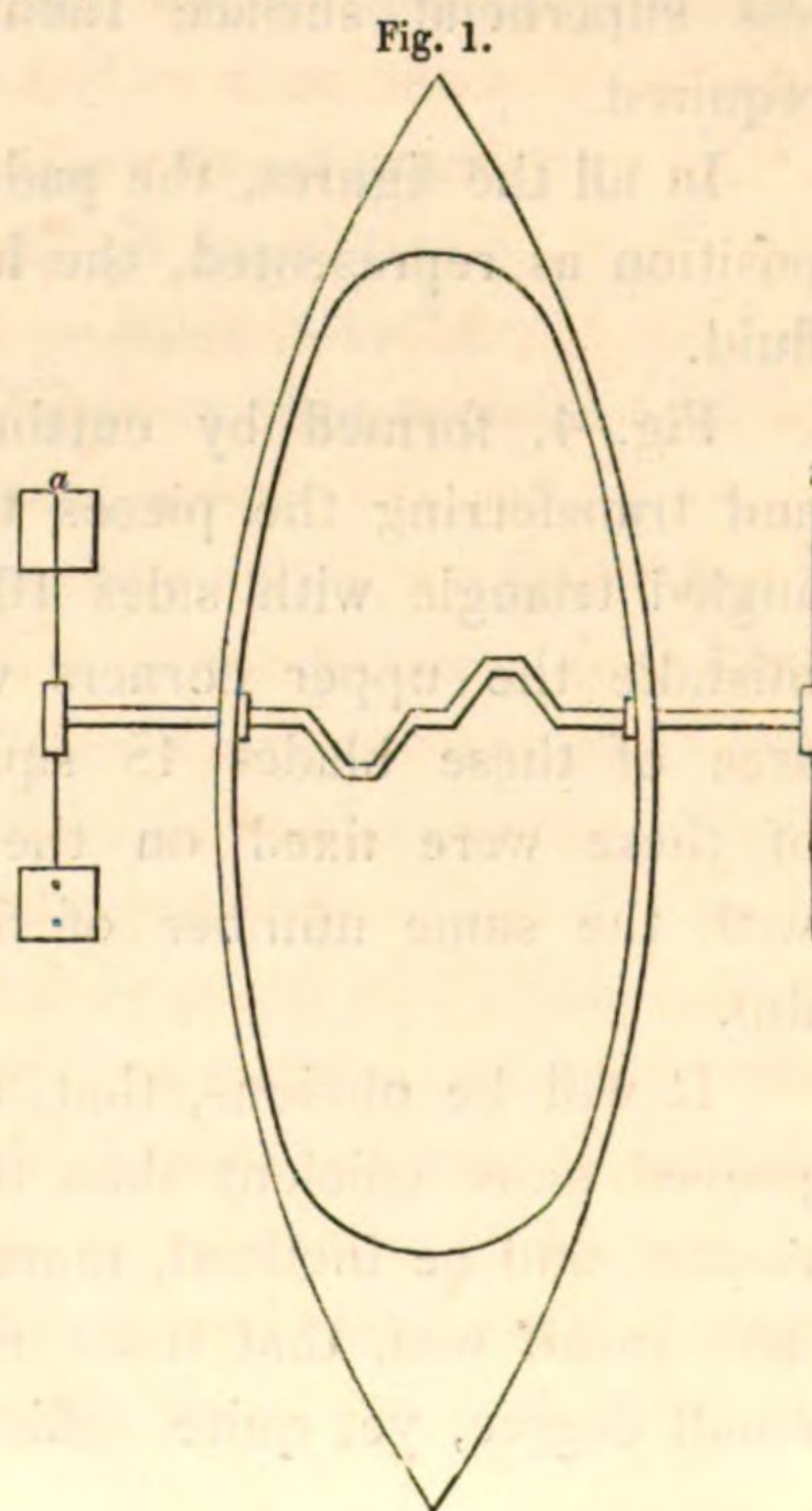
be suspected. Swift and agile she may seem to be, yet much of her power produces no corresponding result in her onward course: like the injured or distorted wings of a bird, malformation in her paddles is fatal to her healthy and rapid flight.

Acute intellects have for years been employed in perfecting marine engines and boilers; but the true figure of propelling blades is a subject that has escaped general attention; sources of retardation were not imagined to be lurking there; the virtue of form in them has not been thought of; in short, while speed is desired above all other qualities, the least attention has been given to the organs upon which it depends. Steamers are now so elaborately improved and enriched as to elicit and deserve the sobriquet of 'floating palaces;' but their buckets are the same rude affairs as were used in primeval paddle-wheels. In endeavouring to quicken their pace our efforts have resembled those of trainers of race-horses, who should confine their attentions to the animals' heads and trunks instead of developing and strengthening the muscles of their limbs.

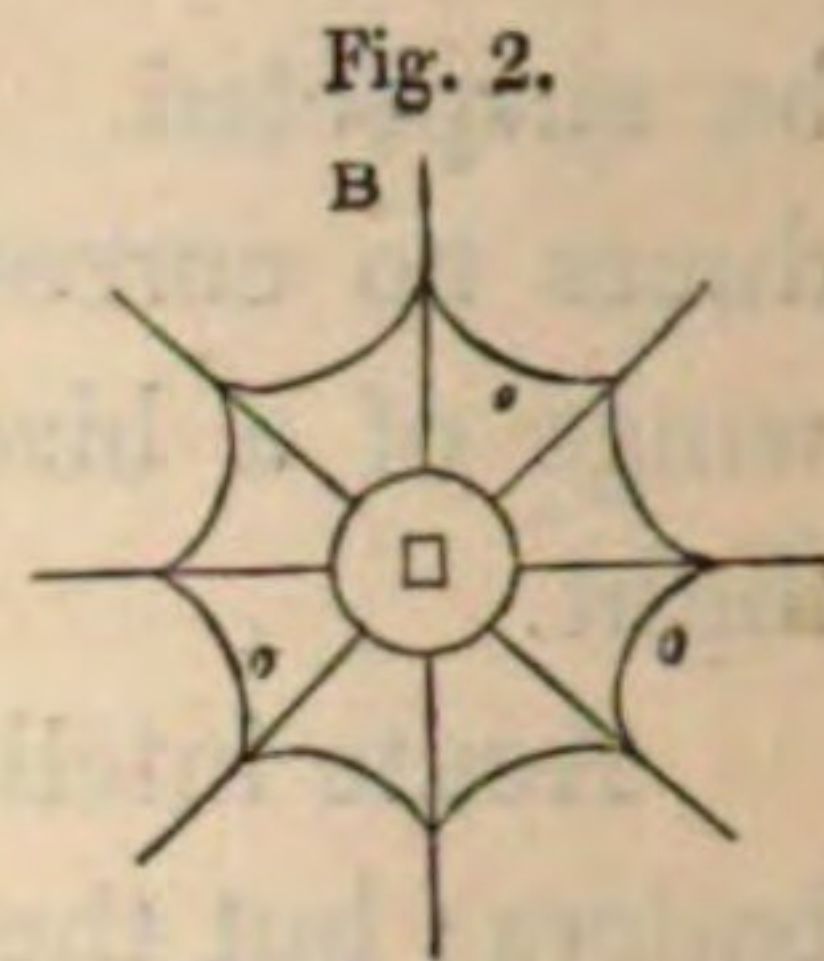
EXPERIMENTS ON THE PADDLES OF STEAMERS,—THEIR FIGURE, DIP, THICKNESS, MATERIAL, NUMBER, &c.

MADE ON THE HARLEM RIVER, NEW YORK, IN 1848.

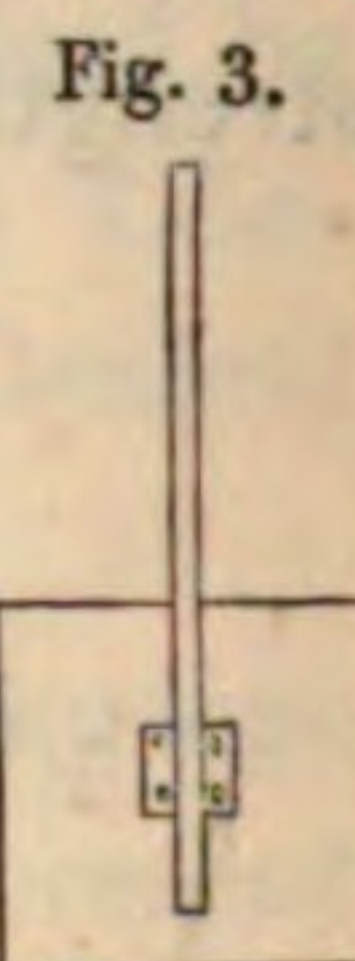
For this purpose the boat fig. 1 was employed. It was $12\frac{1}{2}$ feet long and $3\frac{1}{2}$ feet across the middle; a wrought-iron shaft, 1 inch square, with a crank, extended across the gunwales, and turned in bearings bolted to them; each end of the shaft stretched 14 inches over the side of the boat, which prevented the wheels that were secured on each extremity from throwing as much water into the vessel as if they had been nearer, and afforded a better opportunity of observing the action of the blades: a person seated at one end of the boat readily turned the wheels in either direction, by alternately pushing from and pulling towards him two upright rods, which moved in joints at the bottom of the boat, and were connected to the cranks by horizontal rods or pitmen.



The wheels were very light, and of the simplest construction: one is figured at B; light slender arms, of $\frac{5}{16}$ square iron, with their inner ends cast in the central piece, extended 20 inches from the centre, and thus making a 40-inch wheel. To stiffen them, and transmit any strain upon one to the whole, they were braced tightly together by the wire, *o, o, o*, fig. 2, which was wound round each arm, and retained by slight notches at the corners; the various blades or paddles were cut out of strong sheet iron; square sockets, to slide over the arms, were riveted to the paddles, by which means they were readily adjusted and secured at uniform distances from the axes. All were of the same area, 49 inches.

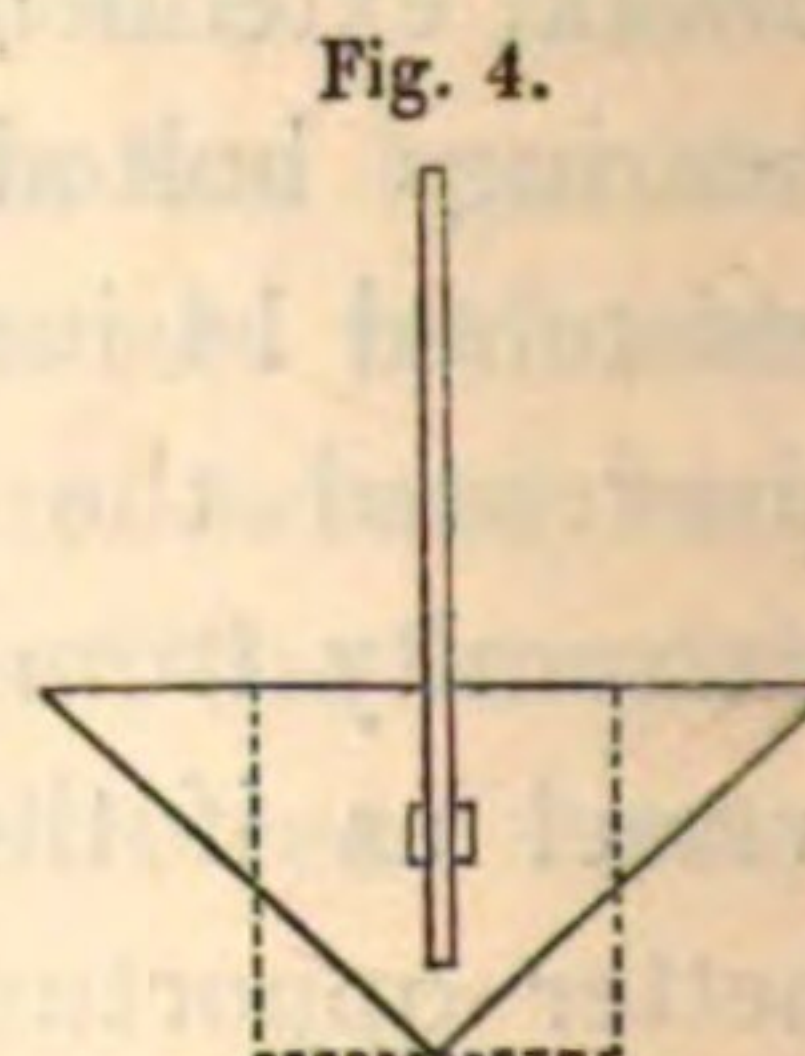


To test the qualities of the boat, and get her into working trim, blades 7 inches square (fig. 3) were fixed on the arms of both wheels, and several excursions up and down the river made with them: their dip was 7 inches or rather more, for their upper edges were half an inch below the surface. They were next removed from one wheel and left on the other, as the standard by which to compare the effects of different shaped ones. They were distinguished as No. 1. Nearly all the rest were formed from them, *i. e.* by removing portions from one part and adding them to others, as will be seen in the following diagrams. In this way there was no danger of making, through mistake, one set of blades of larger or of less superficial surface than others, since no calculation of their areas was required.



In all the figures, the paddles are supposed to sweep through the water in the position as represented, the lowest sides being those which descend lowest in the fluid.

Fig. 4, formed by cutting off the lower angles of fig. 3, and transferring the pieces to the upper ones, making a right-angled triangle with sides 10 inches and hypotenuse 14. (By mistake the upper corners were cut away, so as to leave the area of these blades 48 square inches instead of 49.) Eight of these were fixed on the wheel (see *b*, fig. 1), to compete with the same number of fig. 3, on *a*, both having $7\frac{1}{2}$ inches dip.



It will be obvious, that, as both sets were attached to the same shaft, if one proved more efficient than the other, the boat would be turned from a straight course, and be inclined, more or less abruptly, to the weaker or less efficient set. The result was, that those marked fig. 3 overcame fig. 4, and though only in a small degree, yet quite sufficient to establish their superior effect on the vessel's

progress. As we were not always out of the influence of tides and slight breezes, each experiment embraced excursions in various directions on the river. Once or twice the boat went straight as an arrow, but eventually the square paddles got the better of the triangular ones: these dipped into the water with little noise, and threw it off behind from their points.

Most of the experiments were made in smooth water, and (except slight currents—aqueous and aerial) under most favourable circumstances. Two persons occupied the boat, and the greatest care was exercised in preserving the shaft in a horizontal position. When results were doubtful the experiments were repeated, and generally several times.

The same paddles (fig. 4) were next attached to the arms in the position represented in the margin, and distinguished as fig. 5, the upper side being, as in all other instances, 13 inches from the centre of the axis. Through repeated trials they overcame the test-paddles (fig. 3), and in a rather more marked manner than fig. 3 surpassed fig. 4, they entered the water silently: observers on shore thought they raised more water behind, but did not raise it as high as fig. 3: their points were nearly 3 inches lower in the water than the lower edges of fig. 3. The boat described a circle of 400 feet, and another of 600.

Fig. 5.



The same blades were next tried as fig. 6. From the experiment fig. 5, it was inferable, that if inverted the effect of the blade on the boat would be augmented, as a larger portion would have a longer sweep through the water. Such was the fact, and to such a degree that first two, and then four, were removed from the arms, when the remaining four were found equal to the eight of fig. 3. The plates were next raised till their lower edges were on a level with those of No. 1. In that position 2 inches of their upper extremities were above the surface of the river; but notwithstanding they had a decided advantage, even then, over the square ones.

Fig. 6.



Lastly, the same blades were turned into the position of fig. 7, being fig. 4 reversed. The boat was turned on No. 3 under all circumstances, describing circles from 80 to 150 feet in diameter. Four of them equalled eight of No. 3. They were thought to throw off more water behind than their competitors, which, from the greater extent of their extremities, was probably true.

The next form tried was fig. 3, placed in the position of fig. 8. These turned the boat round against the test ones, in circles varying from 50 to 200 feet. We then tried six of them against the other eight, when there was little observable difference in the result. Four were found superior, but three were unequal to them. These of course entered the water without jarring, and threw it off at their points. It was thought that they threw up more than fig. 3.

Fig. 7.

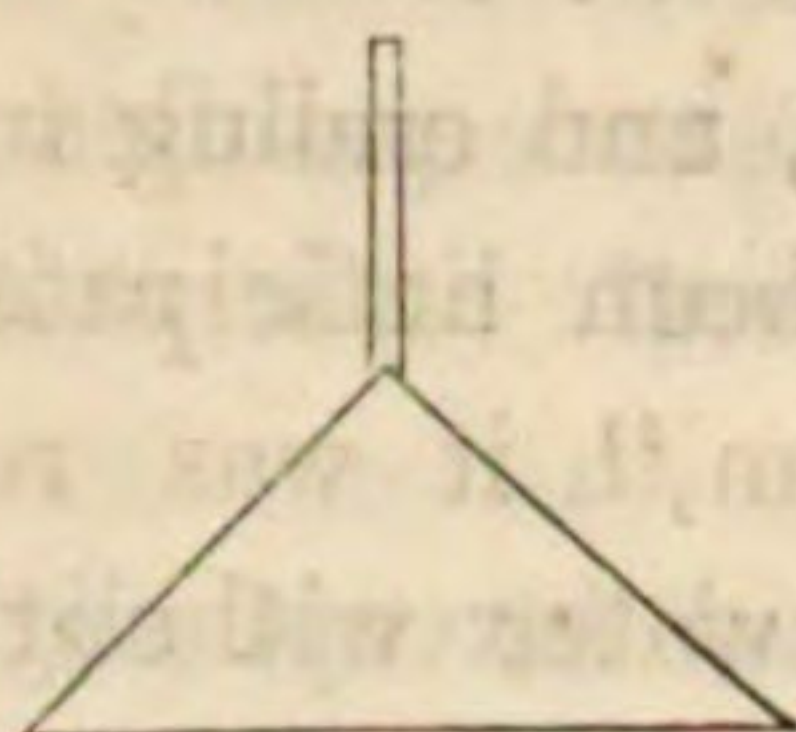


Fig. 8.

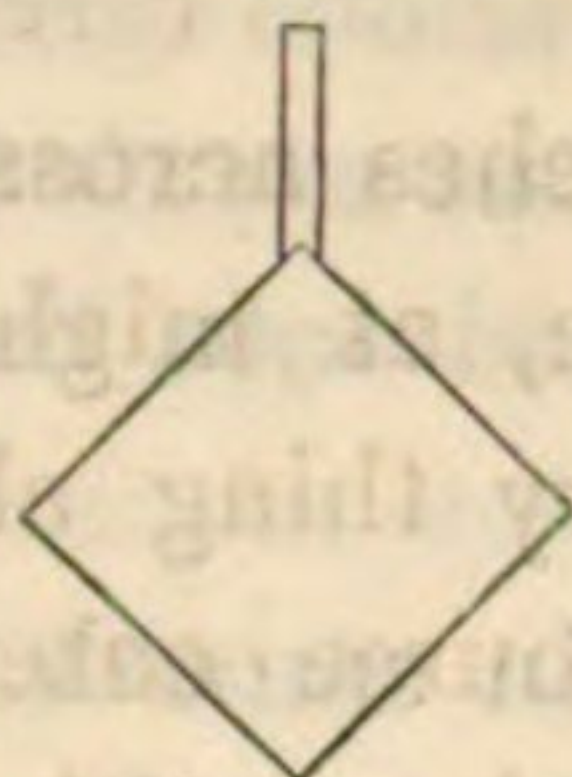


Fig. 9.



Fig. 10.

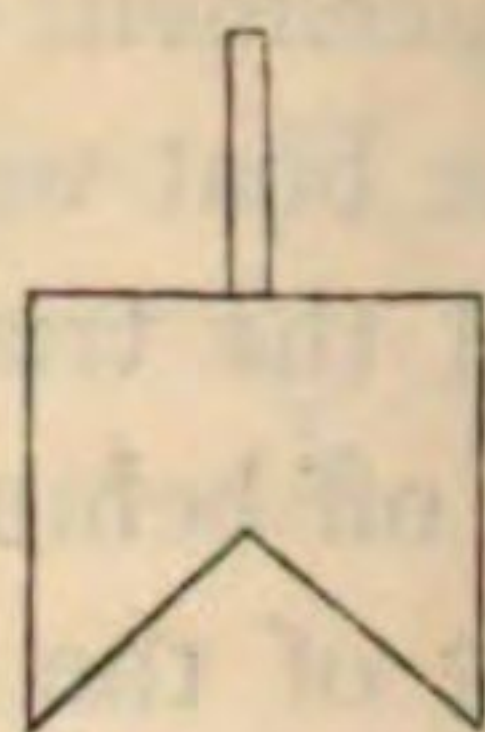


Fig. 9, formed by removing the upper corners below, as in the figure, seemed to have the advantage of fig. 8; but as light winds troubled us, we felt some hesitation in pronouncing them better. Four were superior to eight of No. 3. It was supposed that a slight accession of resistance to the lower ends, sweeping through the water, might be derived from opposing currents meeting in the forks; but we had no means to ascertain if it existed.

Fig. 10, cut out of plates 8 inches square, with one-fourth (minus a superficial inch) removed, as shown in the figure. After several excursions, these were thought to exhibit a very slight advantage over fig. 3; but from subsequent tests they seemed to be balanced. We, on another day, reversed them, as

Fig. 11, which had a decided preponderance over their competitors. Six predominated slightly over the latter, and four were thought nearly equal to them. There was a difference of opinion on the last point, some thinking they were quite as effective as the opposing eight.

Fig. 11.

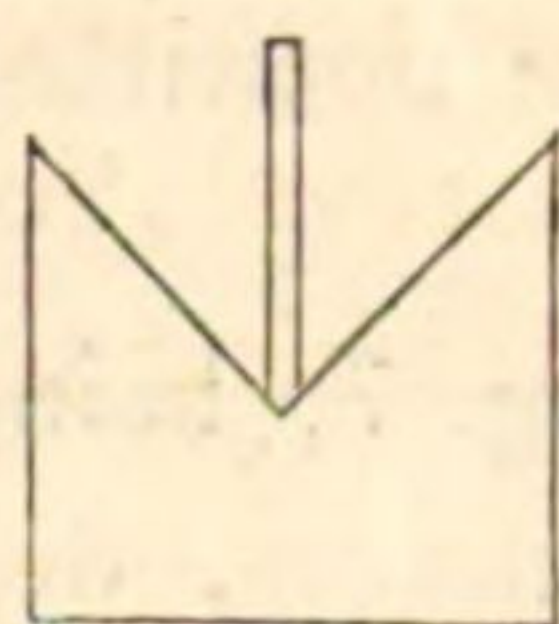


Fig. 12.

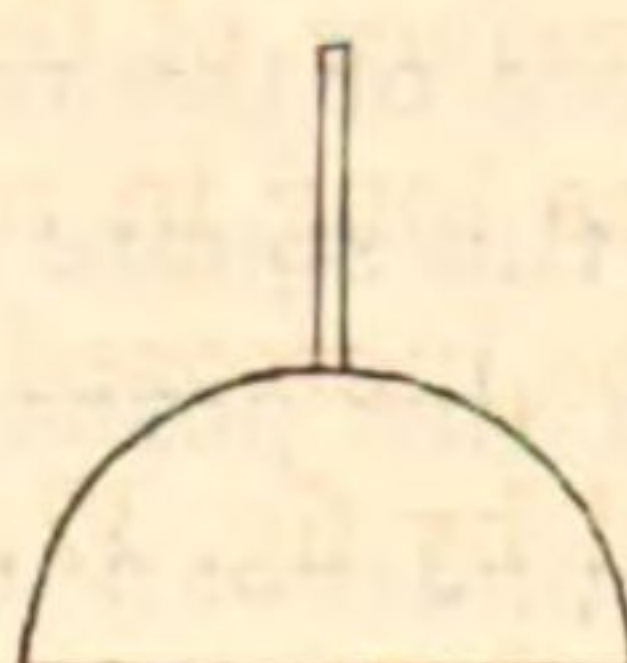


Fig. 13.

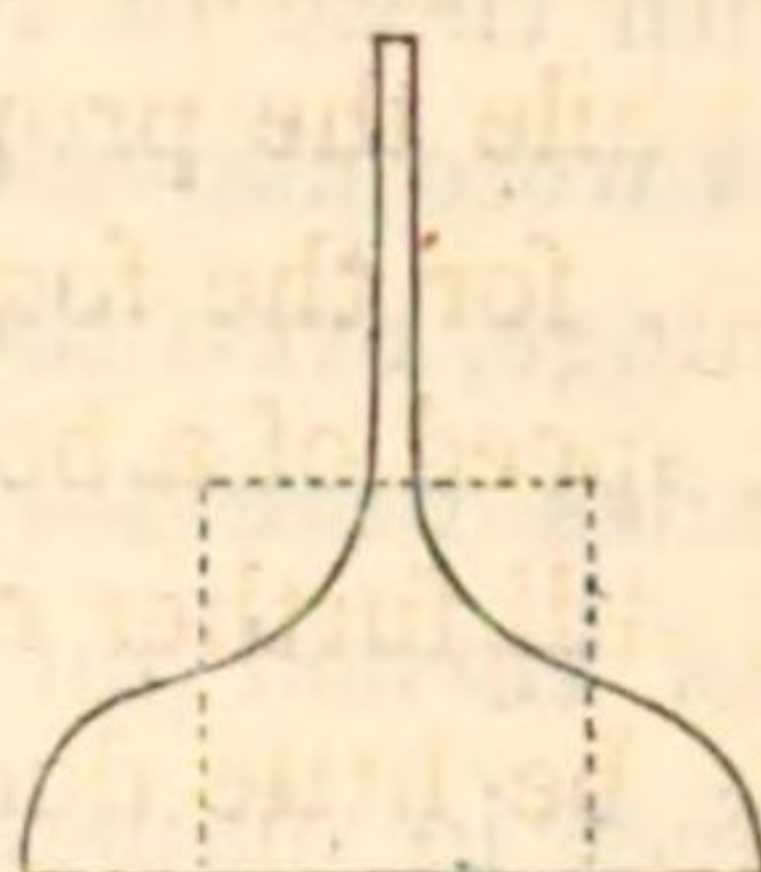


Fig. 14.

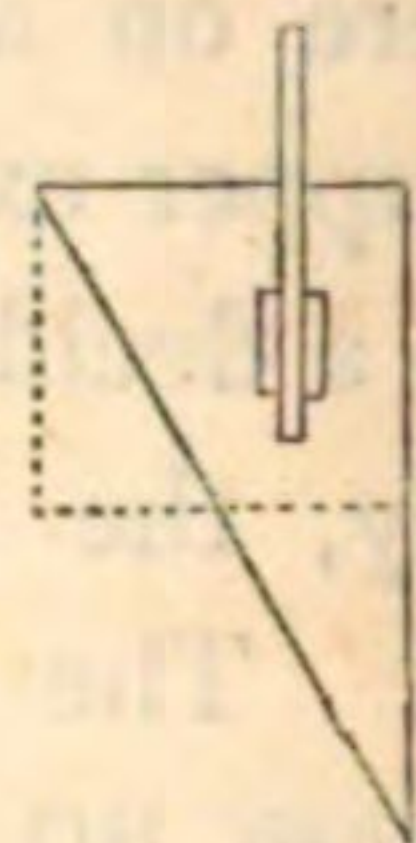


Fig. 12 was a semicircle. When tested, they turned the boat in circles varying (from light winds and tides) from 30 to 150 feet. Four were thought sometimes equal, and sometimes superior, to eight of fig. 3. It is demonstrable that these blades are less effective, though in a very small degree, than those marked fig. 7, and, when reversed, more powerful than fig. 4.

Fig. 13, formed as represented, but not tried, as it was evident their value

would be nearly that of fig. 7, probably a shade above them, but too minute to be detected, except in perfectly still water.

Fig. 14, a right-angled triangle, 7 inches across the top, and ending in a point nearly 14 inches below it. These were, as might have been anticipated, more effective than those of fig. 3. "Every thing about them," it was remarked, "shows their superiority." They of course entered the water without jarring. The same were attached to the arms in the position of fig. 15, and were unable to compete with fig. 3: the latter had a slight advantage over them.

Fig. 15.

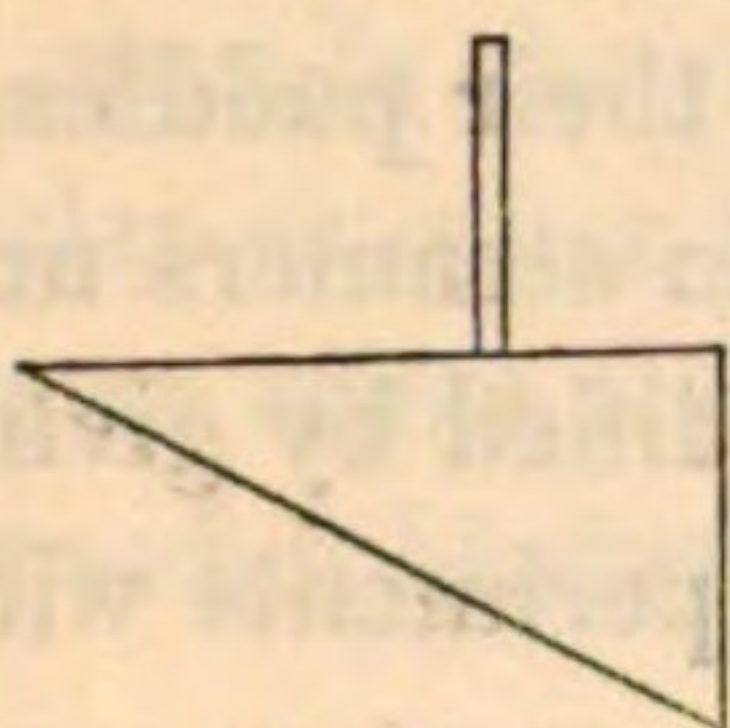


Fig. 16.

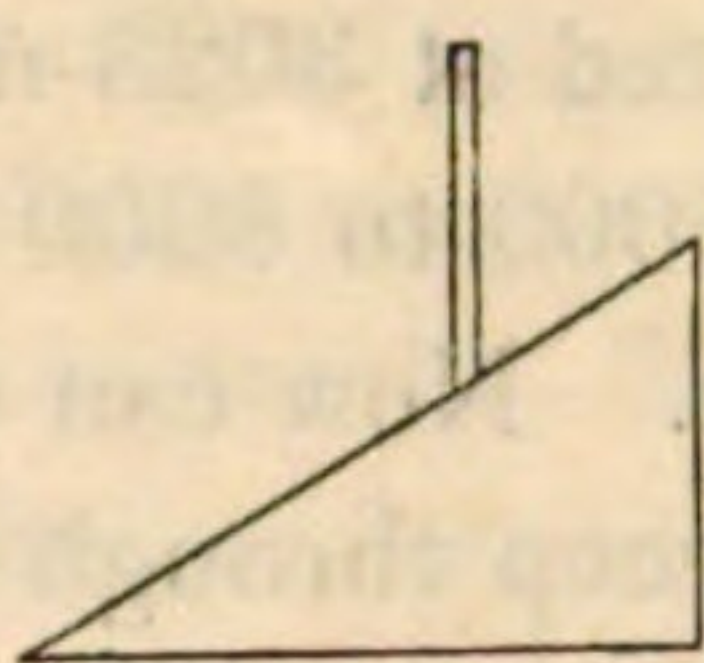


Fig. 17.



They were next reversed as fig. 16, when they proved effective as figs. 7 and 12, four being equally so as the eight opposed to them.

They were finally changed to fig. 17, when the boat was turned so rapidly as to make it difficult, with a wide oar, to keep her in one direction. Four were removed, and then she described a circle in less than 50 feet. Two more were taken away, leaving only a couple to act against the eight on the other wheel, and to which they proved equal.

From these experiments it appears, that with equal areas and equal dip, triangular blades may be rendered twice as effective as ordinary rectangular ones. This is made manifest by figs. 7, 12, and 16, four of the former equalling eight of the latter: and this, too, while the propelling surface of the smaller number was only half that of the greater; for the four were as long in making a revolution as were the eight. Hence the speed of a boat may be increased by diminishing the number of her paddles—a fact still further elucidated by fig. 17.

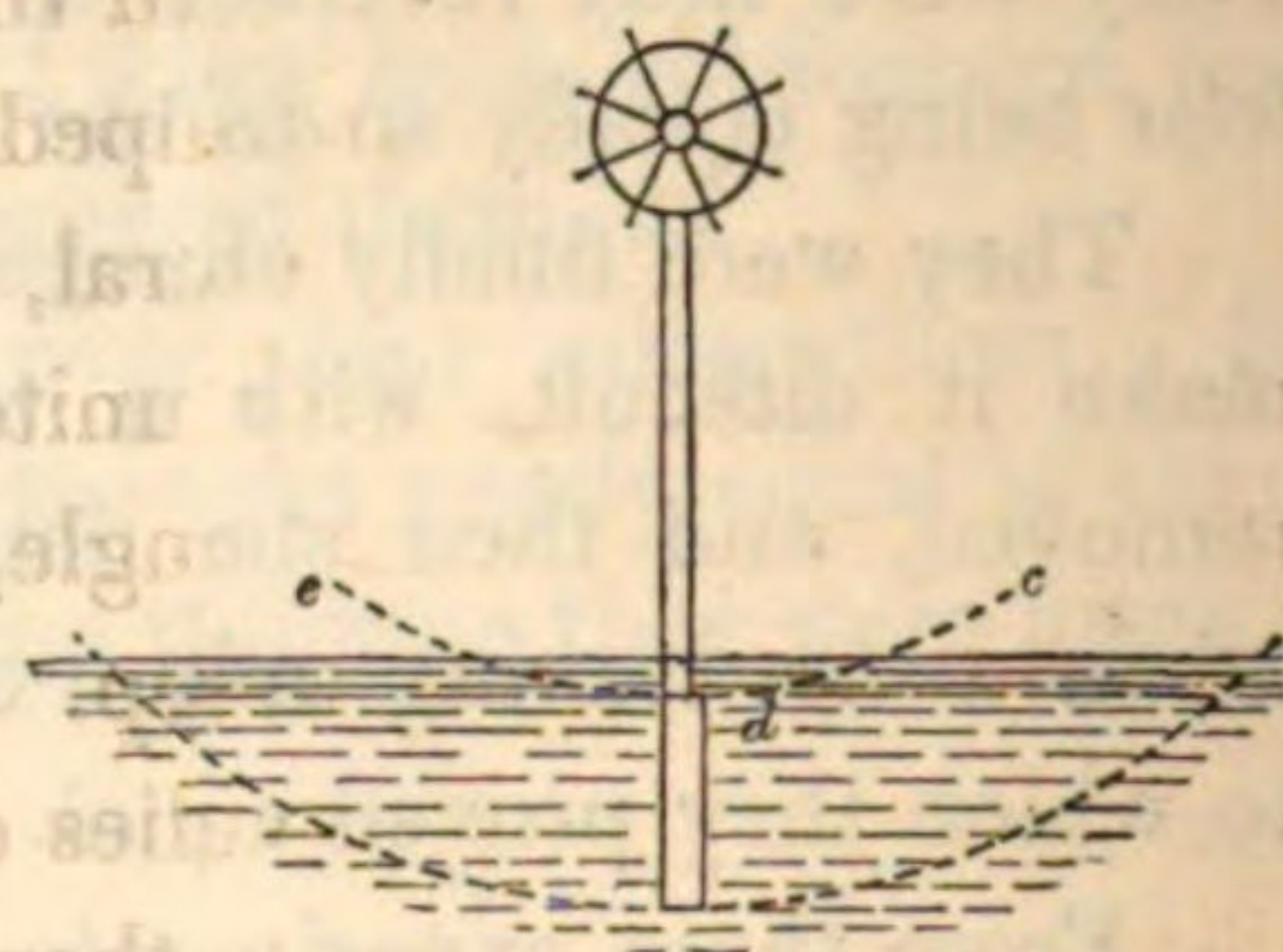
There can, I think, be little doubt, that the greater the velocity of a steamer's wheels, the fewer (within certain limits) should be the blades, and that, at the rate at which some revolve, the number might be reduced with advantage: some have three, others four, and in more than one vessel, without any load on board, I have seen six submerged at each wheel. In these cases, is it not evident that each blade, on entering, plunges, not as it ought, into water undisturbed, but into that which preceding ones have already broken up and set in motion towards the stern? It would seem that one in the act of plunging, another sweeping under the hull, and a third leaving the surface, are all that are necessary to be kept up; and that a

greater number, as regards the speed of a boat, is positively injurious: yet, under a vague idea of attaining a higher speed, the number of paddles has frequently been nearly doubled.

Snow, as every person knows, causes the wheels of land locomotives to slip upon, instead of rolling over, the rail: they revolve as usual, but the carriages make little progress; hence much of the power spent on them is expended to no purpose. So it is with paddle-wheels: a boat never progresses in the ratio of their revolutions, because of the yielding medium in which, and against which, they act: they slip always—a result to some extent inevitable when massive solids wade through fluids. The distance between the Atlantic Steamers' Docks, in Liverpool and New York, has been calculated at 3023 miles; but their paddles, in each trip, pass over a space varying from 5000 to 8000 miles.¹ In steamers unaided by sails the disproportion is often greater. Now can this be modified by giving the paddles a better hold on the fluid they sweep through? The experiments with blades 5, 6, 7, 8, 9, 11, 12, 14, 16, and 17, furnish replies to the interrogatory.

The moral of the foregoing experiments is this: as the propelling power of a paddle is greater at its lower or outer extremity, and diminishes to nothing at the surface, so its face should enlarge with the dip, and be nothing, or next to nothing, above. Let *d*, fig. 18, represent the end of an ordinary blade or paddle: its upper part barely touches the water, and only for the moment it is in the position shown. But suppose it were immersed to the line *e, c*, say 4 or 5 inches, it would even then be no sooner under than above the surface again, so brief would be its immersion. The lower edge, in the meanwhile, would sweep along the extended curve there delineated.

Fig. 18.



¹ The English steamer 'Europa' reached New York after the remarkably short trip of eleven days. Her wheels are 32 feet in diameter; and taking their revolutions at the average of seventeen per minute, her paddles swept over a space exceeding 5000 miles. The steam ship 'Northener' has wheels 31 feet in diameter. In running from New York to Charleston, 630 miles, they made 52,000 revolutions, in another trip 51,000. The 'Cherokee's' wheels are of the same dimensions. In her first trip, to Savannah, a distance of 700 miles, they made 53,000 revolutions. The practice now is, to lessen the slip of marine carriage wheels, and make them approach nearer in effect to those used on land, by increasing their width, that is, the length of their paddles. Hence those of the 'Atlantic,' one of the large Liverpool liners, are 12½ feet long; but for the difficulty of entering the English docks, they would have been 14 feet. Those of the 'Hermann' and 'Washington,' of the Bremen line, are respectively 8 feet and 7½ feet; while the 'Franklin' has them 12 feet. The English mail boats, the 'Europa' and her three associates, have paddles between 8 and 9 feet.

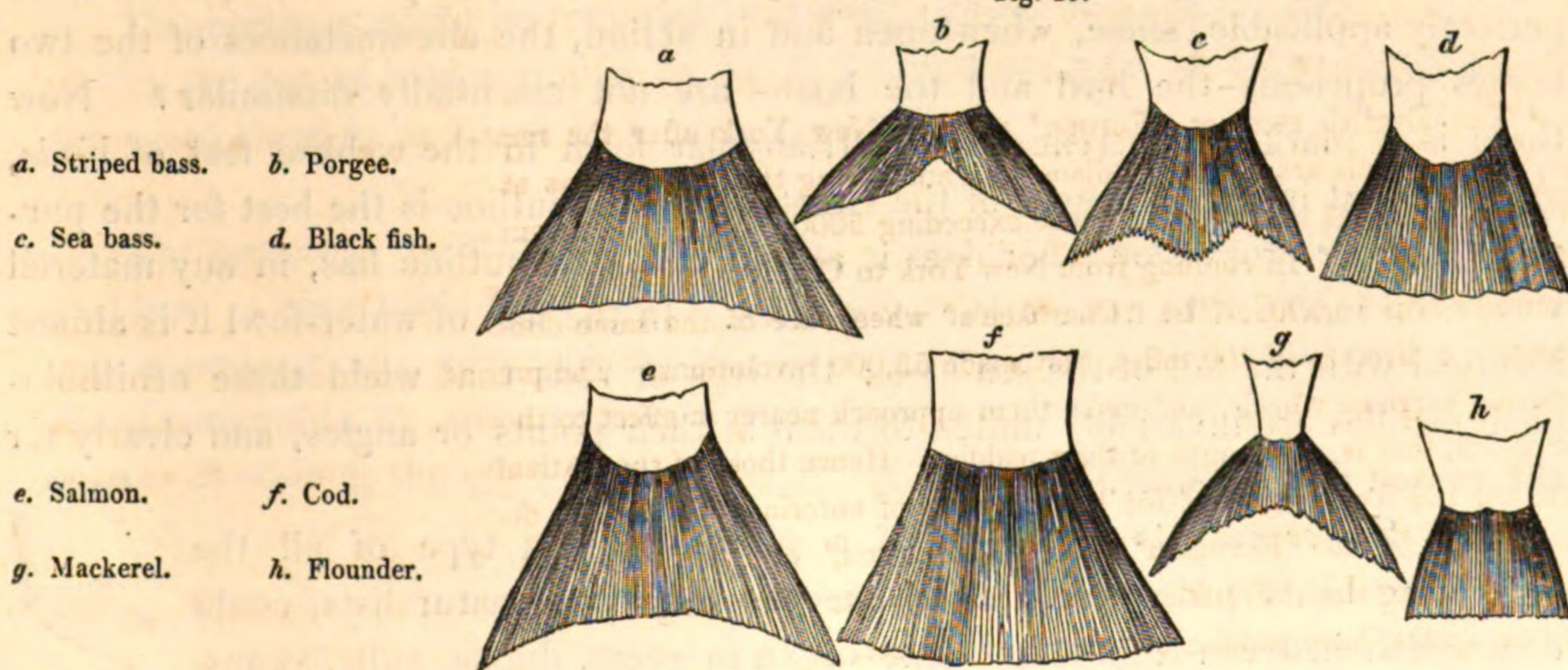
Of what use, then, to make the upper part of a blade of equal extent with the lower? Why accumulate surface where it is of little avail, and withhold it where it is most wanted?—expending materials and power without any adequate return, if not at an absolute loss. The quantity of water carried over a wheel is certainly greater by ordinary than it would be by triangular paddles. The popular form and position of paddles are unphilosophical, if viewed simply as propellers: embrace the same area in any other outline,—in a circle, ellipse, square, pentagon, hexagon, octagon, or other polygonous figure, and the propelling properties would be increased, and the jar arising from their striking the water also diminished.

If the long parallelogram be preferred because of the ready application of wooden planks, then is the principal sacrificed to an accessory,—the greater to the less. If triangular or other improved blades require the adoption of plates of metal, would it be wise to reject them on that account? But of this by-and-by. We shall see that thick wooden blades ought to be condemned on account of defects inherent in them.

But what is this expansion of the lower part of a paddle, and contraction above, but Nature's own plan? In the tails and fins of fishes, in wings of birds and insects, and especially in the palmipeds, she has nowhere sanctioned a rectangular propeller; all are inclined to equilateral, scalenous, or isosceletic triangles, or are made up of them; nor does she ever unite the levers that work them to their sides: the junction is invariably at an angle, and the reason is apparent, that the largest surface may have the longest sweep.

With this view the bodies of fishes taper down to meet the blades, retaining only sufficient muscle to work them. Waiting one day for the cars to proceed to Harlem, I stepped into a neighbouring fish-market and sketched the following from specimens on one of the stalls: I am ashamed to acknowledge that, till then, I was

Fig. 19.



ignorant of the exact forms of these natural propellers, although most of them had passed under my observation on a thousand occasions. Too many of us spend no more thought on the infinitely curious and instructive mechanisms submitted by the Creator to our inspection daily, than does the ox on the vegetable glories he feeds on. The sentiment applies not more to religious than to physical truths,—“Light shineth in darkness, and the darkness comprehendeth it not.” We grope as if blind for that which is patent before us.

The general outlines and proportions are given in the preceding figures; the dimensions of course vary with the age and growth of individuals. The figures denote the width and length of the expanding tails; the latter being taken from the termination of the body, as shown by the curves, which reach more or less into the tails, *i. e.* to strengthen them where strength is most required.

I confess I had no idea of meeting with figures so closely allied to the artificial ones which I had found most effectual as propellers: with the exception of the first two, the whole approach to equilateral triangles.

In the absence of a more extended acquaintance with the minuter aqueous and subaqueous organisms, the nearest of natural analogues to steam vessels seem to be the principal swimming birds. These glide through two elements at once: their long and heavy bodies, adapted to float gracefully on water, are provided with organs of propulsion placed far behind their common centres of gravity—the cause that makes them such awkward travellers on land. When a gale blows in the direction they wish to pursue, like human navigators, they take advantage of it,—they spread their wings to catch it, and are driven onward then, as steamers are, by both wind and paddles.

The reciprocating action, and the expanding and collapsing features of their aqueous organs of progression, are supposed to be unsuited to the magnitude, materials, and velocity of artificial ones: perhaps they are, but may not their contour be perfectly applicable, since, when open and in action, the circumstances of the two bodies propelled—the bird and the boat—are not essentially dissimilar? Now there is a marked adherence to the triangular form in the webbed feet of birds, showing that in the judgment of the Creator such an outline is the best for the purposes of their propulsion; nor does it appear that this outline has, in any material way, been modified to meet other exigencies. In the feet of water-fowl it is almost identical with the tail of the sea bass: the legs or rods that wield these ornithological paddles are invariably united to them at their points or angles, and clearly for the reason already stated.

Fig. 20.

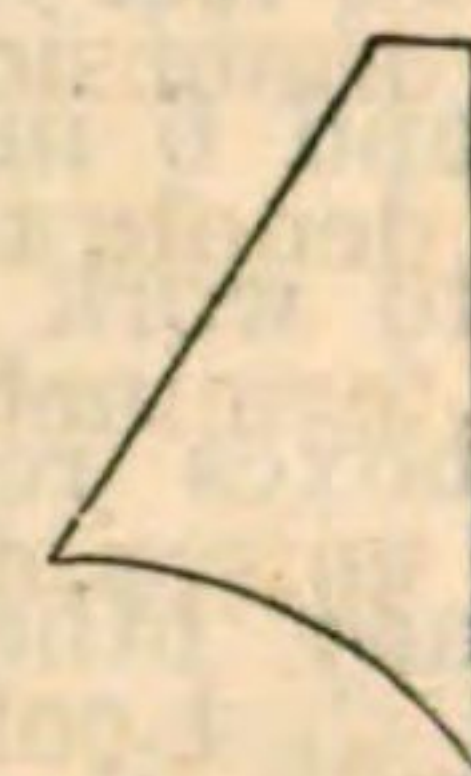
Fig. 20 represents the foot of a petrel: it is a type of all the swimming birds' propellers. Few, except professional naturalists, could distinguish between it and the same organ in geese, ducks, gulls, swans,



the albatross, cormorant, diver, flamingo, &c., &c. Although natural paddles are submerged when at work, and those of our wheels emerge into air to repeat their strokes, I doubt if a more efficient form could be given to the latter than the above: the cusped extremity would obviate the jar consequent on straight-edged blades striking the water.

If I had to fit propellers to a new boat, they should resemble figs. 7, 6, or 17; or I would rather make them like half the foot of a swimming bird, as fig. 21; the perpendicular sides being next the vessel, that the greatest strain might be nearest to the power. Such blades would not be raised out of the sea by a vessel's rolling, nor when submerged be subject to excessive strainings, as common ones are. They would produce no concussion, or but little, on dipping, and would be twice as effective as the same area employed in the prevailing form and fashion.

Fig. 21.



If the principle were required to be adopted in the present paddles, it could be done at a trifling cost. I would remove portions from the upper sides and attach them below, somewhat after the manner shown at figs. 22, 23, 24, and 25.

Fig. 22.

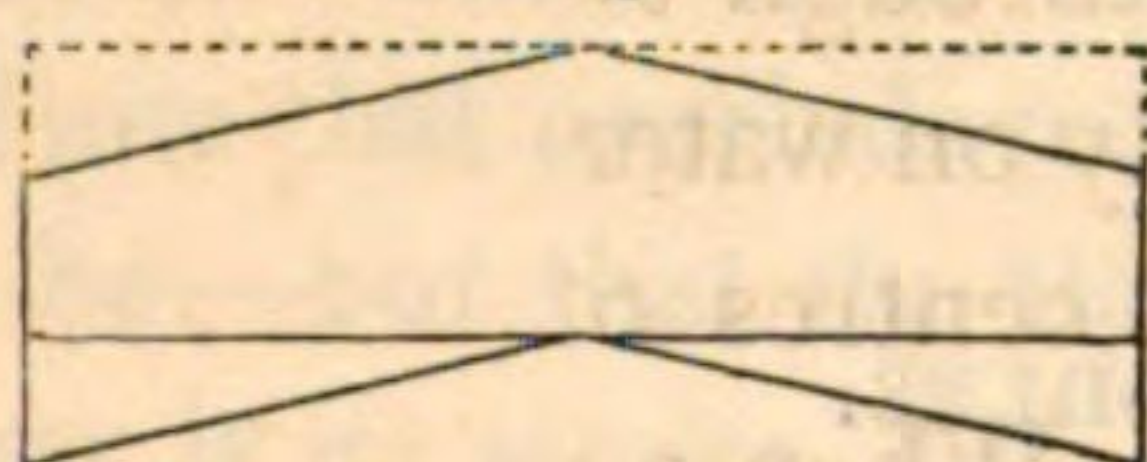


Fig. 23.

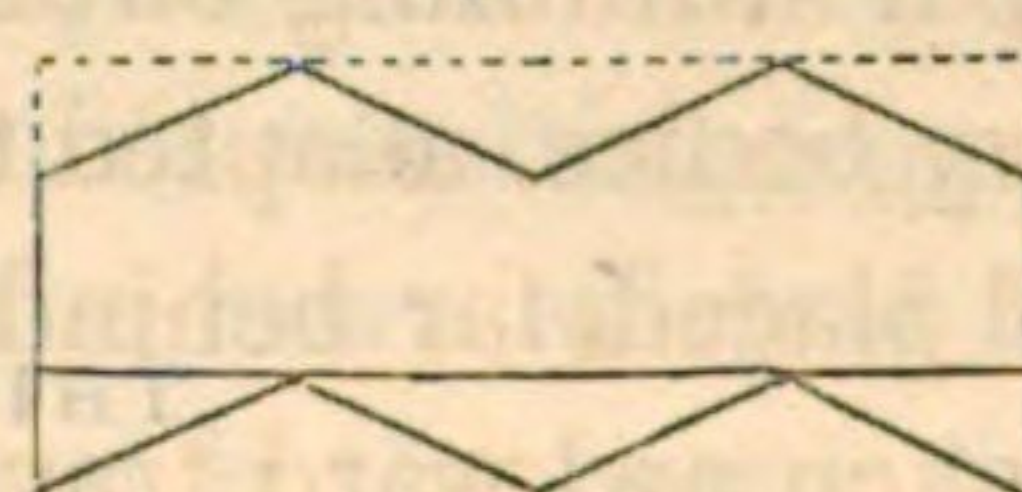


Fig. 24.

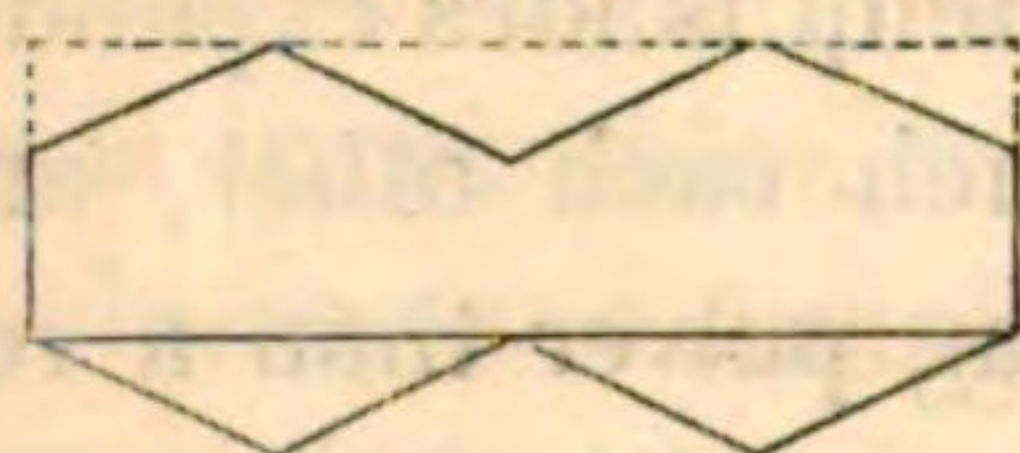
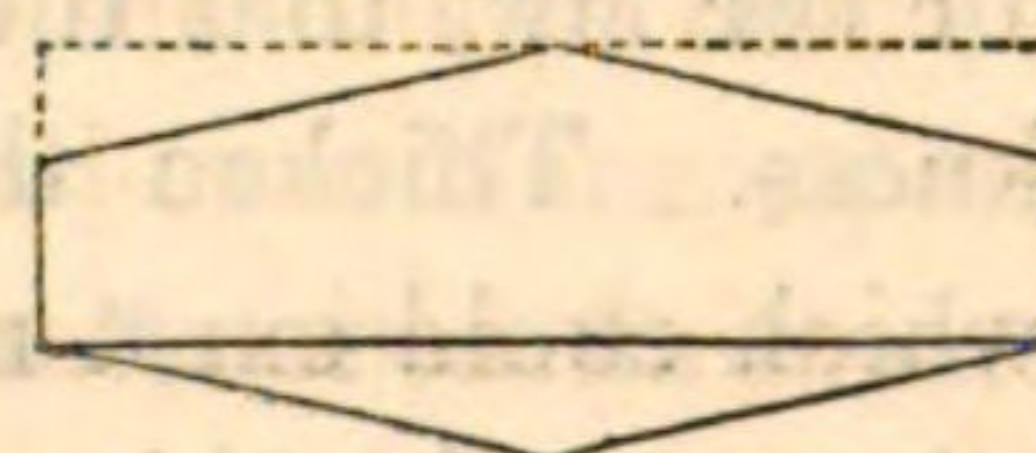


Fig. 25.



The portions might be removed by curved instead of straight lines.

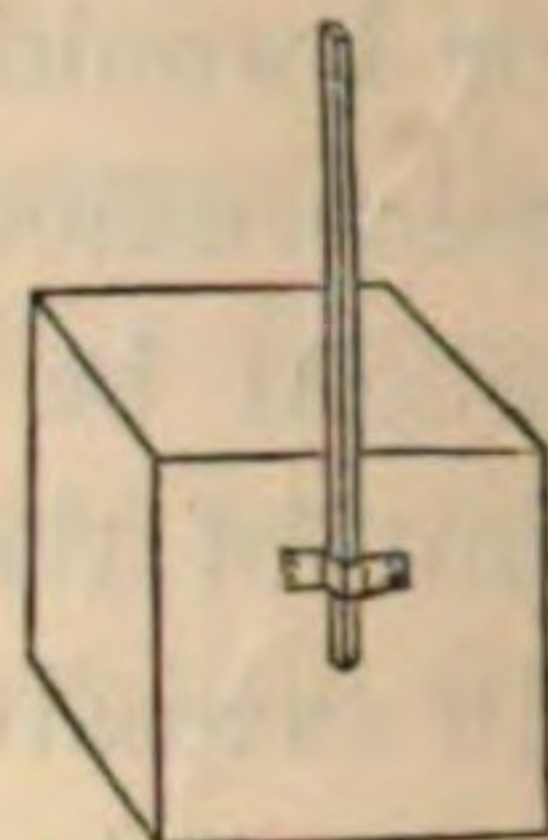
In the use of blades similar to fig. 7, I would vandyke their lower edges, as at 23, point them as at 25, or fork them as at 22.

The foregoing experiments and remarks relate chiefly to the figure and dip of paddles. Other traits next solicited investigation, and though neither prominent nor promising any adequate reward for the requisite labour, they were thought worth attending to, since engineers will certainly be urged to cast about for every means of adding, though ever so little, to the speed of steamers.

BUOYANT OR DISPLACING PADDLES.

It had been imagined that the resistance which fluids oppose to the sinking of bulky bodies in them might be employed as an element of propulsion,—that if close barrels, for example, were fastened to the arms of a wheel, their ends would act as paddles, and the force required to plunge them (equal to 62 lbs. for each cubic foot of water displaced) also react favourably on the boat. To test this idea, eight square and tight boxes, fig. 26, 7 inches by 7, and 6 inches deep, were secured to the arms of one wheel, and set to work against the eight blades, No. 1 (fig. 3), on the other. The boxes required very sensibly more power to carry them round than any other tried, and were miserably deficient in pushing the vessel forward with it,—certainly not equalling four of the competing blades: they produced quite a commotion in the water, carried large quantities over with them, and, could we have communicated sufficient velocity, would probably have formed a vertical ring of water. These boxes were and should be considered simply as unusually thick blades. All paddles are buoyant in proportion to their thickness.

Fig. 26.



THICKNESS OF PADDLES.

But though worthless in one respect, they were valuable in another, for they led us to the fact, or the law, that the propelling virtue of blades expands and contracts with their thickness. Thicken them till they touch each other, and they form a perfect drum, which could exert no more propelling power than a revolving grindstone; reduce them to the thinnest plates consistent with the strains they have to oppose, and in the same ratio their propulsive quality is augmented.

The boxes were removed, and boards $\frac{7}{8}$ ths of an inch thick and 7 inches square put in their places: these represented common plank paddles, and were found sensibly inferior to their metalline competitors, whose thickness was slightly less than $\frac{1}{16}$ th of an inch. We next took away two of the latter, when no very obvious change in the boat's direction occurred: when two more were taken off, the remaining four were unable to contend with the wooden ones. These, it will be remembered, were $\frac{1}{7}$ th the thickness of the boxes, and consequently inherited that proportion of their defects.

It was also very observable how much more water was raised by the boards than by the plates: it could not be easily cast off their blunt boundaries, but kept running over them from one side to another,—a fact rendered more distinct in the boxes. Nothing could declare plainer, that the sharper the dipping edges of paddles

are made, the more back-water they throw off at the point where its departure is most beneficial; that is, when the reaction favours the vessel's progress, and consequently less is carried higher than the axis: a very little labour would impart this feature,—in other words, would make their section a wedge. The resulting benefit would repay the expenditure a hundredfold.

Compared to metal, wood approaches in its nature to sponge; water clings to it, its pores are absorbing vessels that suck it in, and assist to retain it on the surface.

Here Nature also confirms the positions arrived at. Extreme tenuity of blade is stamped with perfection by her. Hence we see it strengthened by reticulated bars in the wings of insects,—by radial, angular, and tapering ribs in the fins and tails of fishes. An uniformly thick and unsupported slab, like our paddles, is nowhere met with: we cannot imagine natatory or soaring organs formed after such a pattern without perceiving the absurdity.

The caudal propellers of fishes are necessarily thick where they join the bodies; but how rapidly is the substance diminished, and to a mere film at their extremities,—so much so, that they are often there torn and jagged by accident or wear, as fishermen well know: there must therefore be some powerful reason for withholding the material one that overbalances all inconveniences resulting from its absence; and what can it be—but that the thinner the blade the more efficient it is as a propeller—the longer is its stroke, and the more effectual is the power that wields it? The same law prevails in the wings of birds,—their outward boundaries are feathered off to almost nothing.

The reflection is irresistible—with what nicety and care Nature perfects her propellers, and how clumsy and unfinished are ours; as if, forsooth, a vessel's progress did not depend upon them.

The last two experiments demonstrate, that the less water a paddle displaces by its volume, the more efficient it is; that all accumulation of material behind its acting face, beyond what is absolutely necessary to strengthen it, is injurious and ought to be avoided. But how does this accord with the current practice? Oaken planks are universally employed, and I have heard more than one engineer assert, that the thicker they are the better: "because," said they, "if the propelling property be not enhanced, its power is not enhanced, and the additional weight is a positive advantage, since the heavier the wheels are, the easier they work, the more uniform their movements."¹

¹ As a further indication that the value of thinness in blades, and of their disencumbrance from every pound of material extraneous to their functions as propellers, has not hitherto been appreciated, it may be remarked that similar observations were made in my hearing, thus: "A few tons of wood in the buckets

The 'Gorgon,' an English steamer, had "large wheels and little power," so she used oak or pine scantlings, 5 inches by 6, or 6 by 8, for paddles. Had her managers been aware of the true effect of thick blades, they never would have adopted them with the view of economizing power.

Paddle planks vary in thickness from $1\frac{1}{2}$ to 3 inches: no sea steamers have them less than 2 inches. In the English vessels they are $2\frac{1}{4}$; in others, as the 'Franklin,' they are $2\frac{1}{4}$; in some of the largest class they are 3. The 'Atlantic' and the 'Pacific,' each of 3000 tons, for the Collins' line, are to have them 3 inches. The former is to have twenty-eight blades; hence, united, they will form a solid mass, 7 feet thick in each wheel—just one-fifth of its diameter: they are to be $12\frac{1}{2}$ feet long by 34 inches: those of both wheels will therefore contain nearly 500 cubic feet of timber, and must displace that enormous volume of water at every revolution by their submersion alone; and, as we have seen, not only uselessly, but with a serious retardation of the vessel's headway, and waste of her motive power.

The wheels of the 'Pacific' are 36 feet in diameter: each will have thirty blades $11\frac{1}{2}$ feet by 3 feet: the solid contents of her paddles will therefore equal 517 cubic feet; her loss from the same source will consequently be greater. In every revolution of each of her wheels her paddles will lose $7\frac{1}{2}$ feet of effective stroke, and those of the 'Atlantic' 7 feet. Those of the ocean steamer 'United States' are $2\frac{1}{4}$ or $2\frac{1}{2}$ inches thick; they are thirty-six in number, but as they are split and attached on both sides of the arms, there are really seventy-two. The effective stroke of her blades is certainly diminished from 10 to 15 feet in every turn of each of her wheels, startling as the assertion is.

Has the attention of engineers ever been turned this way? or, have they forgotten that a volume of water equal to that of a boat's paddles, and every inch of material submerged with them, is neutralized as a resisting medium as often as it is displaced by their immersion,—that water is to them what steam is to pistons? The more space the latter occupy in cylinders, the shorter becomes their stroke, because metal then takes the place of steam; the object to be moved crowds out the mover. Thicken a piston till it fills its cylinder, and the motive agent being wholly kept out, all motion ceases.

It is much the same with the paddles of a wheel: let them fill up $\frac{1}{10}$, $\frac{1}{5}$, $\frac{1}{3}$, or $\frac{1}{2}$ of the circle they describe, and in those proportions they lose their virtue, because

do no harm, if they do no good: they add weight to the wheel, which is desirable, and their only disadvantage is the additional load on the boat." I believe this is the general, if not the universal, opinion of engineers. But the experiments just referred to teach us, that if a wheel require loading, the load should be attached to those parts of the arms that revolve about the surface. They cannot enter the water without becoming drags on the blades.

in the same proportion they displace or push aside the fluid agent on which their worth depends.

The 'Atlantic' will lose 7-feet stroke in every turn of her wheels. I leave to mathematicians to determine how many more miles an hour she would make if the loss were reduced to 7 inches, by using $\frac{1}{4}$ -inch iron in place of 3-inch plank.

The paddles of United States large steamers are invariably of 3-inch plank. The language of the Chief Engineer on this point, under date of January 1849, was as follows: "The blades of large wheels for marine steamers are usually, and ought to be, 3 inches thick." The average number in each wheel, he observed, is twenty-eight. Hence it is demonstrable that nearly 12 per cent. of the power employed in these vessels is thrown away, and with it even a larger proportion of their enormous cost and attendance when in active service.

There are several interesting questions about paddles that yet require solution, but as respects their thickness there is no mean to seek; the thinnest is the best under all circumstances,—thin, were it possible, as a lamina of mica. The only question is, what material will supply the thinnest sheets to resist the pressure they are to oppose? Plates of steel may yet be adopted, and perhaps coated by the electrotrope process with copper or other metal.

To one remark, an examination of some steamers' wheels adds force. The accumulation of bolts, nuts, clamps, straps, stays, and other things on and about the backs and faces of the paddles—sometimes even to bolting a new plank, or part of one over an old one,—shows that those who heap on matters of the kind are not aware how much the efficacy of blades is thereby diminished. They forget that they should be thin and smooth as plates of glass, and that every inch of matter introduced between them is an evil. It is impossible to view the disjointed, broken, patched-up slabs of some vessels without exclaiming, "What a saving of power and increase of useful effect would not the substitution of a suitable sheet of metal for each accomplish!"

In some vessels—the United States mail-steamer 'Galveston' is one—strips of plank are bolted over the ends of the paddles to prevent their splitting or warping. As they do not diminish the faces, but merely form elevations upon them, they are doubtless considered as in no degree interfering with the propelling function. We now perceive that when such things are necessary, they should be of iron, and let into the blades, so as to be flush with their surfaces.

A new division of engineering might judiciously be made, and paddle-making be recognized as a distinct department. These instruments have certainly never received the attention which they merit. Speed is the great desideratum, and it depends on them. Engines, and all the mechanism of a steamer, are subservient

to them; and yet, while everything else has been elaborated to the utmost, they have been all but overlooked.

NUMBER OF PADDLES.

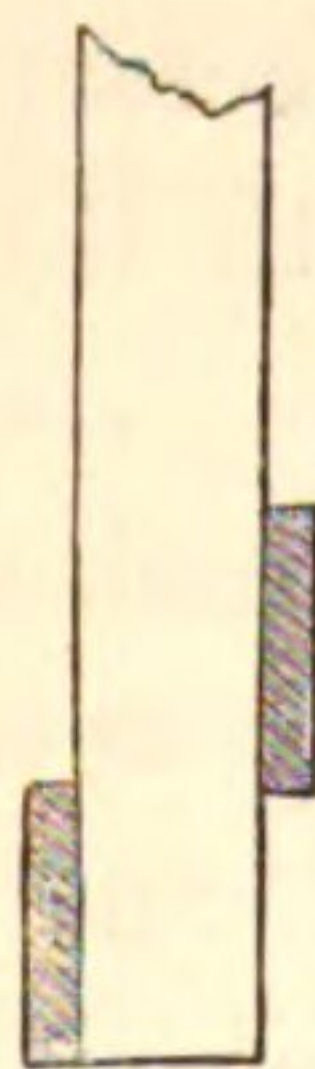
The experiments of each day evinced that so far as propulsion is concerned, the fewer the paddles the faster went the boat, so long as one at each wheel, or an area equal to the face of one, was kept in full play. A greater number in the water merely cuts it into slices, throws them into commotion, and diminishes the resistance they should oppose to the blades. As a further elucidation of this fact, four blades, 7×14 , were tried against the eight test ones, 7×7 . The smaller number had a decided advantage over the greater, and the cause was visible: they had a full sweep through an unbroken, undisturbed mass of fluid, and consequently produced, unabridged, their legitimate effects; while those on the other wheel—unusually small ($\frac{1}{3}$ or $\frac{1}{4}$) as their number was, compared to those on the wheels of steamers—following so quickly in the wake of one another, threw it into an uproar, causing eddies, whirlpools, and counter-currents, and thus interfering with each other, necessarily produced inferior results.

We thought eight of fig. 4 would be equally valuable as twenty-four of fig. 3, but the construction of our wheels prevented us from instituting a series of similar comparisons.

The number of paddles now employed is generally greater than formerly: for large vessels twenty-eight are usual; some have twenty-four, and others thirty-two. The English rule, said to be a good one, is adhered to by many American engineers, except when circumstances require a deviation. By it there is a paddle for every foot of a wheel's diameter, which makes them stand 3 feet apart: there are boats in which they occur every 2 feet.

One object of their multiplication is to equalize the jar of their striking the water, by increasing the number of the blows. With the same view they are often divided through the middle, lengthwise, and the inner half, that next the shaft, removed to the opposite side of the arm, as in the end view, fig. 27, thus doubling,

Fig. 27.



in a manner, their number. All the British steamers have their blades thus arranged. The 'Hermann's' twenty-eight were thus made into fifty-six: their efficacy was found to be reduced about 9 per cent. The value of the upper or inner halves has been ascertained to amount to about the same, for, when wholly removed, the lower portions have proved within 10 per cent. as effective as before. The blades of the 'United States' are split, and disposed as in the figure. The true principle of breaking the jar of paddles striking the water seems to me

to be indicated in the blades 4, 5, 8, 9, 10, 14, 15, 21, 22, 23, 24, 25. Had the attention of engineers been led to it in the early days of steaming, the popular plan of avoiding the evil at the expense of a greater would not have been sanctioned so long.

I noticed the blades of the last-named steamer a week after her return from Europe. Seven were submerged, or fourteen, if those on both sides of the arms be counted. She sailed for New Orleans with eight (or sixteen) under water. The 'Cherokee' left for Savannah with six of her undivided blades below the surface. The 'Washington' came in from Bremen with five similar ones fully immersed on each side, four full ones and the halves of two others. The largest of our Sound and River boats have equal, if not greater, numbers under. The 'Vanderbilt,' 1200 tons, has five, or ten halves, immersed in each wheel, when lying at her dock, and without passengers on board. The 'Isaac Newton,' 1200 tons, has similar wheels, and the same number of blades under water at once.

It is clearly as impossible for a paddle to do its duty when thus embarrassed among its fellows, as for a traveller to make the same progress through a crowd as on an open plain.

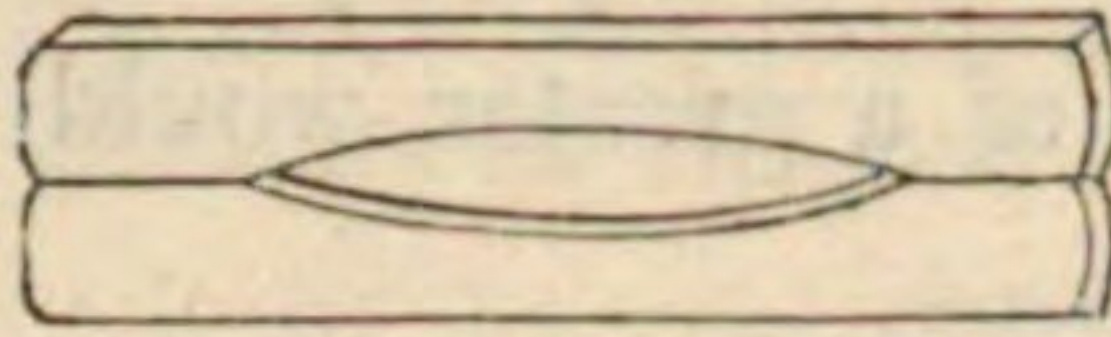
It may be a matter of future interest to place on record this feature, as exemplified in other New York steamers. The following memoranda are from personal observations, recently made.

The 'Hudson' has three undivided paddles under at each wheel.

„ 'Utica' three	do.	do.	do.
„ 'Red Jacket' four	do.	do.	do.
„ 'Cleopatra' four	do.	do.	do.
„ 'Ausonia' nearly four	do.	do.	do.
„ 'Falcon,' U. S. mail, has five, fully down.			
„ 'Galveston,' U. S. mail, do.	do.		
„ 'Confidence' four and a half	do.		
„ 'Oswego' four	do.		
„ 'Kosciusko' three and a half, her arms heavy timber.			
„ 'Erie' four	do.	do.	
„ 'Armenia' four fully down, out of sight.			
„ 'Antelope' three and a half	do.		
„ 'William Young' three	do.		
„ 'Buena Vista' two and a half	do.		
„ 'Admiral' nearly four	do.		
„ 'Warren' the same	do.		
„ 'New Haven' five	do.		
„ 'Hero' three	do.		
„ 'Massachusetts,' (1000 tons,) plying on the Sound, five.			

The 'Alida' three and a half. She is deemed a first-class boat and a quick goer. Her wheels are

Fig. 28.



31½ feet diameter. The blades, 2-inch plank, 10 feet long by 33 inches: each consists of two planks, 16½ inches wide—hence a joint in the middle. A curious example of the mechanical effect of the blades striking the water is

exhibited; a long elliptical portion being worn away in several, as in the figure. Probably imperfect joints admitted the water through them at first, and continued rushing kept enlarging the apertures.

- „ 'Bay State' (1600 tons, plies on the Sound) has the same number of split and divided blades as the 'Newton' and 'Vanderbilt,' that is, ten immersed at each wheel.
- „ 'South America' has eight immersed at each wheel.
- „ 'Buffalo' nine do. do.
- „ 'Empire State' eight; her arms and rings are heavy timber.
- „ 'Oregon' ten, same as the 'Bay State.'
- „ 'Empire of Troy' eight, fully down.

As regards the violent concussion arising from the action of existing paddles, to diminish which their number is increased, to lessen by division the blows, there is a simple mode of reducing it one-half, though, from their unphilosophical and unmechanical figure, it cannot be wholly removed, nor the consequent loss of power avoided. The usual practice is, so to arrange a boat's wheels that two blades, one on each side, strike the water simultaneously. In calm weather, who has not heard these double blows at the distance of several miles? This custom is the converse of Nature's. No swimming or diving bird pushes out both paddles at once; they invariably alternate them,—an imposing and instructive fact. Had any of the palmipeds—those especially that live entirely in water, hunting their prey beneath it, and consequently to whom velocity is indispensable to existence—struck out both paddles at once, the plan of nautical engineers might have been deemed in accordance with correct principles of speed and economy, of material and power; but while they all use but one at a time, it is surely worth while to test by experiments the difference between the two actions.

EITHER BY

BY GEORGE RENNIE, ESQ.

F. R. S., &c. &c.

PADDLE-WHEELS AND SCREW-PROPELLERS.

THE subject of propelling vessels by mechanical power has been fully developed in the early editions of the present work, — in the first instance by Mr. Tredgold, and subsequently by Messrs. Barlow and Mornay. In the ninth Section¹ Mr. Tredgold has based it upon the forms of vessels for stability, speed, capacity, and strength: “it depends,” he says, “upon the kinds of vessels for different purposes,—the resistance and modes of propulsion,—the nature of the engines adapted for vessels,—the strength of their parts,—and the species of fuel and its management to obtain the best effect.” He endeavours to point out the law which governs the stability of floating bodies according to the experiments of Bossut and others, and gives formulæ for their resistance as derived from similar authorities.²

On the subject of propellers, he traces them from the ancient and simple modes of oars and paddle-wheels down to the more complicated system of inclined planes, curved surfaces, and jets of water. He shows that the actions of propellers may either be continuous, as with paddle-wheels and screw-propellers, or alternative, as with oars and jets of water. He states that when the actions are continuous, the area of the surfaces in action multiplied by the resistances must be equal to the area of the vessel by the vessel’s resistance when reduced to the same direction. It is obvious that all those which act at intervals only must require to be of greater area than those which act continuously: “hence, unless there be some other manifest advantage, this circumstance alone must determine us to reject all except the first or continuous class,” in which he includes the screw.

¹ See page 309, vol. ii. ‘Marine Engines.’

² See Professor Moseley’s Paper in the 2nd volume of the Philosophical Transactions for 1850,—‘On the Dynamical Stability and on the Oscillation of Floating Bodies, according to experiments made by Mr. Rawson in Portsmouth Dockyard.’

ON THE EFFECT OF PADDLE-WHEELS.¹

The effect of paddle-wheels is determined by Mr. Tredgold by means of formulæ which represent the velocity of the exterior and interior portions of the floats,—the resistance of one square foot of float-board,—the differential of the effective power and the direct power of the floats, which must be equal to the resistance of the vessel,—or, in other words, of the area and velocity of the centre of pressure of the floats, whereby the power to produce the effect must be equal to the resistance of the vessel. This pressure must in all cases be proportional to the square of the velocity, minus the velocity of the vessel through the water. This law is, however, subject to modifications dependent upon the velocity of the floats and the difference between their plus and minus pressures. The rules given by Mr. Tredgold are not sanctioned by his editor, as they are inadequate to embrace the different cases presented by the action of paddle-wheels in propelling vessels, and for which he substitutes four new equations, by means of which the whole theory is embodied. These equations show, that with given sized paddle-wheels and with given draughts of water, the velocities under all circumstances will be proportional to the cube root of the quantity of steam consumed per minute: a second equation shows that more steam may be consumed by either increasing the length of the stroke or by diminishing the radius of the wheel; while the latter equations indicate a corresponding increase of the velocities in the ratio of the cube root of the increased consumption.

As regards the oblique action, it is shown that the loss does not exceed a fortieth part of the whole, and may be safely neglected, as the mean direction of the action is of greater importance to the motion than the loss of power. He then gives equations for different kinds of floats, such as those of a rectangular, triangular, and parabolic form, showing at the same time that there is an obvious advantage in the latter, as an equal resistance is obtained with a less breadth of float, while the resistance is least when it strikes and leaves the water, and greatest when in a vertical position; and in proposing the parabolic form, Mr. Tredgold derived his idea from its approximation to the fins of a fish, and which are used for impelling in the same manner, so that while the rectangular float strikes the water with its whole breadth, the parabolic float strikes it sooner, and gradually acquires its full hold of the water. The best position for the float is a plane passing through the axis, in order that the resistance or plus pressure may be the greatest possible.

The advantages derivable from large wheels are represented to consist in their more direct action, that they enter and quit the water more freely, and disturb it less.

¹ See page 322, vol. ii. 'Marine Engines.'

And finally, as regards the modifications which have been applied to paddle-wheels for the purpose of getting rid of certain defects, Mr. Tredgold considers that the remedies have generally been worse. He thinks, however, that if a certain degree of elasticity were given to the arms of paddle-wheels, and the floats were made parabolic, they would be a great improvement.

MR. BARLOW'S EXPERIMENTS.

The subject of paddle-wheels was afterwards considered in a very valuable communication made to the Royal Society, and published in the 'Philosophical Transactions,' in 1834, entitled 'On the Motion of Steam Vessels,' by P. W. Barlow, Esq. Impressed with its importance, and of the advantages which might be derived from an inquiry on the subject, Mr. Barlow availed himself of the opportunity presented by his residing in the neighbourhood of Woolwich Dockyard, where many steam vessels were constantly lying. By the aid of the Government, he instituted a series of experiments upon the speed and performance of several of the best steam vessels in the Service; and the results having been frequently verified, they were tabulated so as to show the relative tonnage, horse-power, consumption of fuel, diameter of the wheels, dimensions of the floats, their velocity through the water, the relative velocity of the vessel and the pressure upon the floats, the comparative effect between the common wheel and the vertical or Morgan's wheel,¹ and the ratio of the speed of a steam vessel to the power employed to propel it. These were illustrated by the actual performances of vessels employed in the Post-Office Service between Liverpool and Kingstown, and by those of vessels on long voyages.

The most important, however, are contained in the twelfth Table, namely, on the comparative resistance of a steam vessel with that of a plane surface. The comparative resistances between plane and curved surfaces exposed to the shock of a fluid and moving through it had already been investigated by many philosophers, from the period when Sir Isaac Newton made his experiments on the resistances of a pendulum oscillating in a fluid, down to the more elaborate and extensive experiments of Beaufoy: but we are not aware that any one had, previously to Mr. Barlow, compared the resistances of vessels on a large scale; and the very important conclusions which have been derived from these experiments have enabled us to calculate the elements of resistance in a steam vessel more correctly than heretofore.

"It is evident," says Mr. Barlow, "that when the power of a steam engine is employed in propelling vessels through the medium of a fluid by the reaction of a paddle-wheel, there results an unavoidable loss of a large portion of the power of the engine,—first, by the action of the paddle being oblique or at an

¹ Originally invented by Elija Galloway.

angle with the horizontal direction of the vessel in every position except the vertical one, by which a portion only of the power exerted on the paddle becomes effective ; and secondly, by the receding of the wheel in the water necessary to create a resistance equal to the force applied by the engine. This source of lost power must exist in all paddle-wheels, whatever their construction, from the resistance being created in a fluid ; but the radial paddle being subject to these defects, many contrivances have been proposed to remedy the evil, by causing the floats to keep a vertical position by the aid of machinery during their progress through the water." This remedy has been applied very extensively in the paddle-wheel invented by Galloway, usually termed Morgan's. Similar modifications had been applied by Seaward and Maudslay. As before stated, with the aid of these experiments Mr. Barlow had been enabled to determine and calculate in each case the relative velocity of the wheel and vessel, the actual pressure upon the vertical paddle, the area of paddle per horse-power, and other facts ; and by comparing these data with the velocity, tonnage, &c., a just conception may be formed, not only of the action of each paddle-wheel and the manner in which the power of the engine is expended, but also the amount of surface, proportion of the paddles, dip of immersion, &c., which are required to produce the greatest useful effect. Mr. Barlow then gives formulæ for finding the centre of pressure of a paddle-wheel, by which it becomes easy to calculate the degree of resistance on the paddles at any angle of inclination, and the whole power of the engine, either by obtaining the sum of all the resistances of one paddle passing through the water, and multiplying by the number, or by finding the mean resistance of one paddle in action by the centre of pressure.

The general results of the second Table show that the power expended on the common radial wheel, as compared with the vertical paddle in Morgan's, is in the ratio of .546, .151, and .197 ; that is, in Morgan's wheel *the vertical position is the most effective in propelling the vessel, and in the common wheels the least so*, contrary to the received opinion, the best effect being produced in Morgan's wheel between the angles of 60° and $65^{\circ} 33'$; thus showing in the former case the great quantity of power absorbed by the oblique action of the common wheel, whereas in the vertical wheel the ratio of the whole effect will be that of the velocities of the wheel and vessel in the ratio of 3.2, or .660 of the whole power. This is illustrated by the experiment contained in the third Table, wherein it is shown that when the vertically acting wheel is slightly immersed, little or no advantage is gained, as the additional velocity required to obtain the necessary resistance is fully equal to the loss by the oblique action of the floats in the common radial wheel ; but when the immersion is deep, the loss in the common wheel absorbs .447 of the power, while the loss from Morgan's wheel remains nearly the same. This applies particularly in rough weather, when the loss of the former is great as compared with the

latter. As respects another description of paddle-wheel on the cycloidal principle of Field and Galloway, the results given in the fourth Table contrast favourably with Morgan's in small immersions, and show a greater equality of effect in different immersions, as compared with other wheels. As regards the relation between the diameter of the wheel, the area of the paddle, and the velocity of the vessel, Mr. Barlow shows that when the area of the float of a paddle-wheel is so adjusted to any given diameter, the engine is capable of performing its whole duty, and that this same duty might be performed with a less paddle, a larger wheel, or *vice versa*, but that the velocity of the vessel would be the same in both cases. To determine this question he gives two equations, from which he deduces, first,—that the two velocities are to each other inversely as the square root of the radii; and secondly,—that the new area of paddle will be found to increase and decrease so rapidly that little practical advantage can be taken of the condition of the first equation.

It appears, however, that there are two ways,—one by reducing the paddle, and the other by reducing the diameter of the wheel,—by which, in the former case, the speed of the vessel will remain the same, and by the latter it will be increased as the cube root of the power developed in both cases.

As regards the twelfth Table of experiments, on the comparative resistance of a steam vessel with that of a plane surface, it is shown, that contrary to the results of all experiments hitherto made on a small scale, the resistance of a well-shaped vessel does not exceed $\frac{1}{17}$ th part of a plane of the same sectional area.

The method adopted in arriving at these results is by taking the effective pressure in pounds exerted by the engine, the velocity of the vessel, the velocity of the vertical paddles through the water, the area of the paddle-board, the area of the vertical paddles, and the immersed sectional area of the vessel,—so that by comparing the power required to urge the plane or midship section through the water with the actual power employed by the engine to move the vessel at the same velocity, the difference shows the mere resistance or mobility of the vessel, which difference is shown to vary in different vessels from $\frac{1}{15}$ th to $\frac{1}{24}$ th of the force or power necessary to urge the plane of equal section through the water. These valuable experiments were found to coincide very nearly with those of Colonel Beaufoy, who showed that the force necessary to urge a plane through the water of one square foot area, at the rate of eight nautical miles per hour, was 203·79 lbs. Taking, therefore, the experiments on the 'Medea,' which moved with the velocity of 11·33 miles per hour, or 966 feet per minute, it would require, according to Colonel Beaufoy, (the resistance being as the square of the velocity,) 308 lbs., which being applied to the area of the midship section of the vessel, multiplied into its velocity, and the product divided by the usual allowance per horse-power, would give the power necessary to urge the plane forward at that rate.

The reader is however referred to the Paper itself for the details, of which the foregoing is but an imperfect outline.

ON PADDLE WHEELS, BY A. DE MORNAY, ESQ.

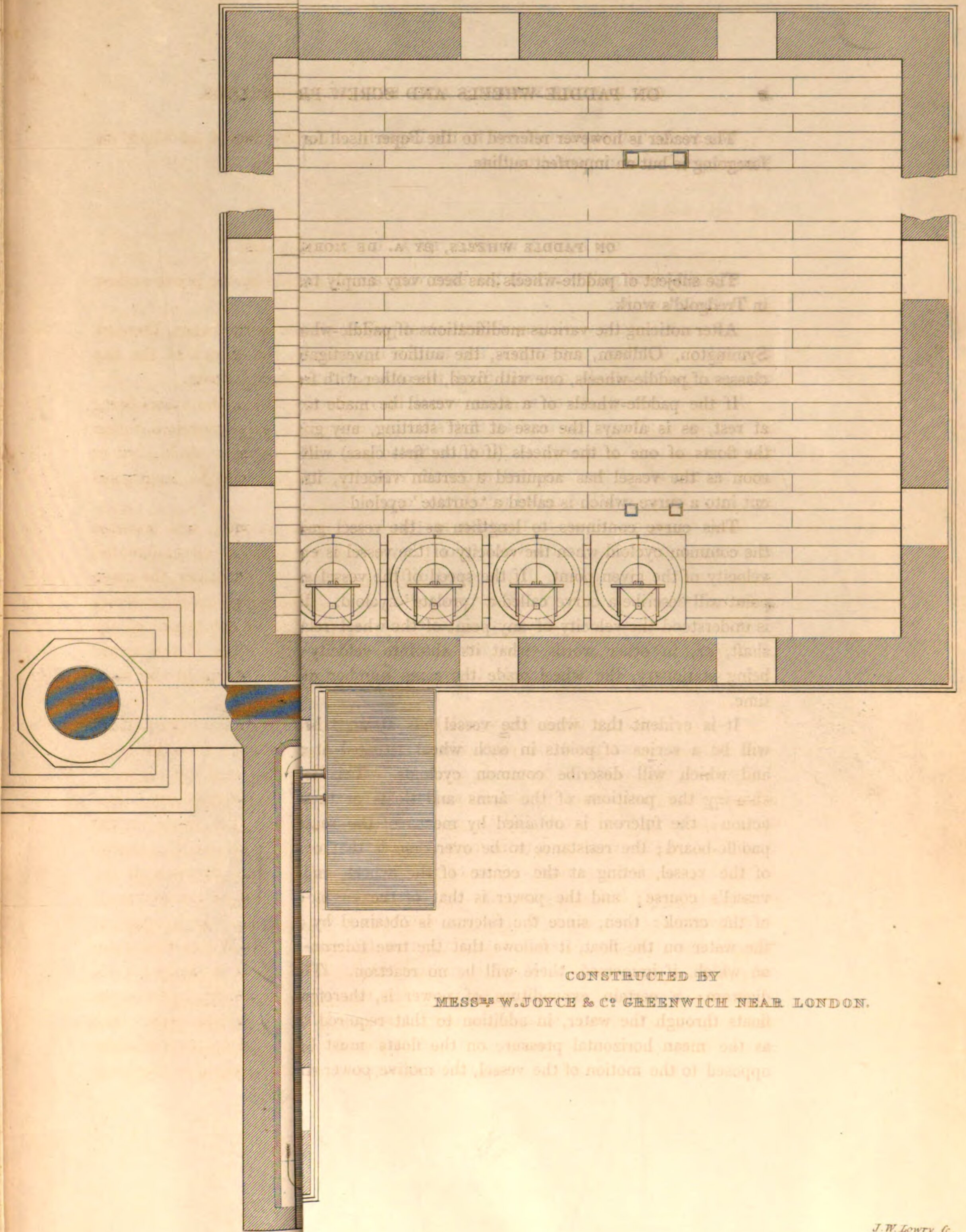
The subject of paddle-wheels has been very amply treated by the above author, in Tredgold's work.

After noticing the various modifications of paddle-wheels by Buchanan, Bernard, Symington, Oldham, and others, the author investigates the theory of the two classes of paddle-wheels, one with fixed, the other with feathering floats.

If the paddle-wheels of a steam vessel be made to revolve, the vessel being at rest, as is always the case at first starting, any given part comprised within the floats of one of the wheels (if of the first class) will describe a circle; but as soon as the vessel has acquired a certain velocity, its path will be lengthened out into a curve, which is called a 'curtate' cycloid.

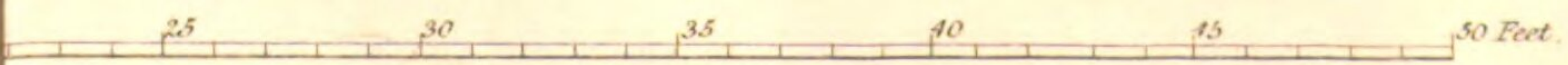
This curve continues to lengthen as the vessel gains velocity, and becomes the common cycloid when the velocity of the vessel is equal to the circumferential velocity of the given point. If the speed of the vessel go on increasing, the given point will describe a curve called a 'prolate' cycloid. By circumferential velocity is understood the velocity of any point of the wheel relative to the centre of the shaft, or, in other words, what its absolute velocity would be, if the centre being stationary, the wheel made the same number of revolutions in the same time.

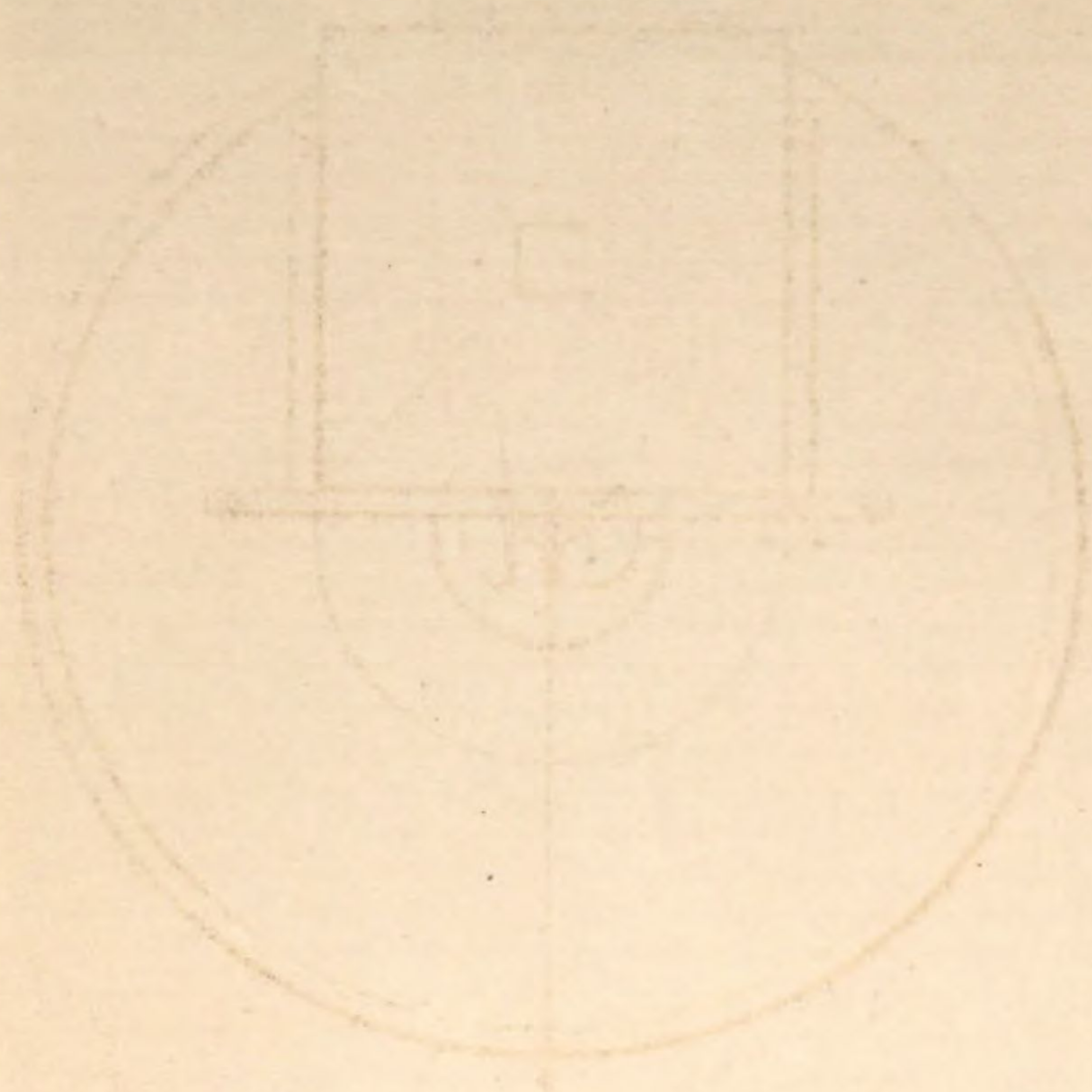
It is evident that when the vessel has attained her maximum speed, there will be a series of points in each wheel situated at a distance from its axis, and which will describe common cycloids. This is illustrated by diagrams showing the positions of the arms and floats as they successively come into action: the fulcrum is obtained by means of the reaction of the water on the paddle-board; the resistance to be overcome is that of the water to the motion of the vessel, acting at the centre of the wheel, and in the direction of the vessel's course; and the power is that of the engine applied at the extremity of the crank: then, since the fulcrum is obtained by means of the reaction of the water on the float, it follows that the true fulcrum is situated at that point on which, if immersed, there will be no reaction. This point is shown in the diagram: a certain expenditure of power is, therefore, necessary to force the floats through the water, in addition to that required to propel the vessel; and as the mean horizontal pressure on the floats must be equal to the resistance opposed to the motion of the vessel, the motive power must be equal to the mean



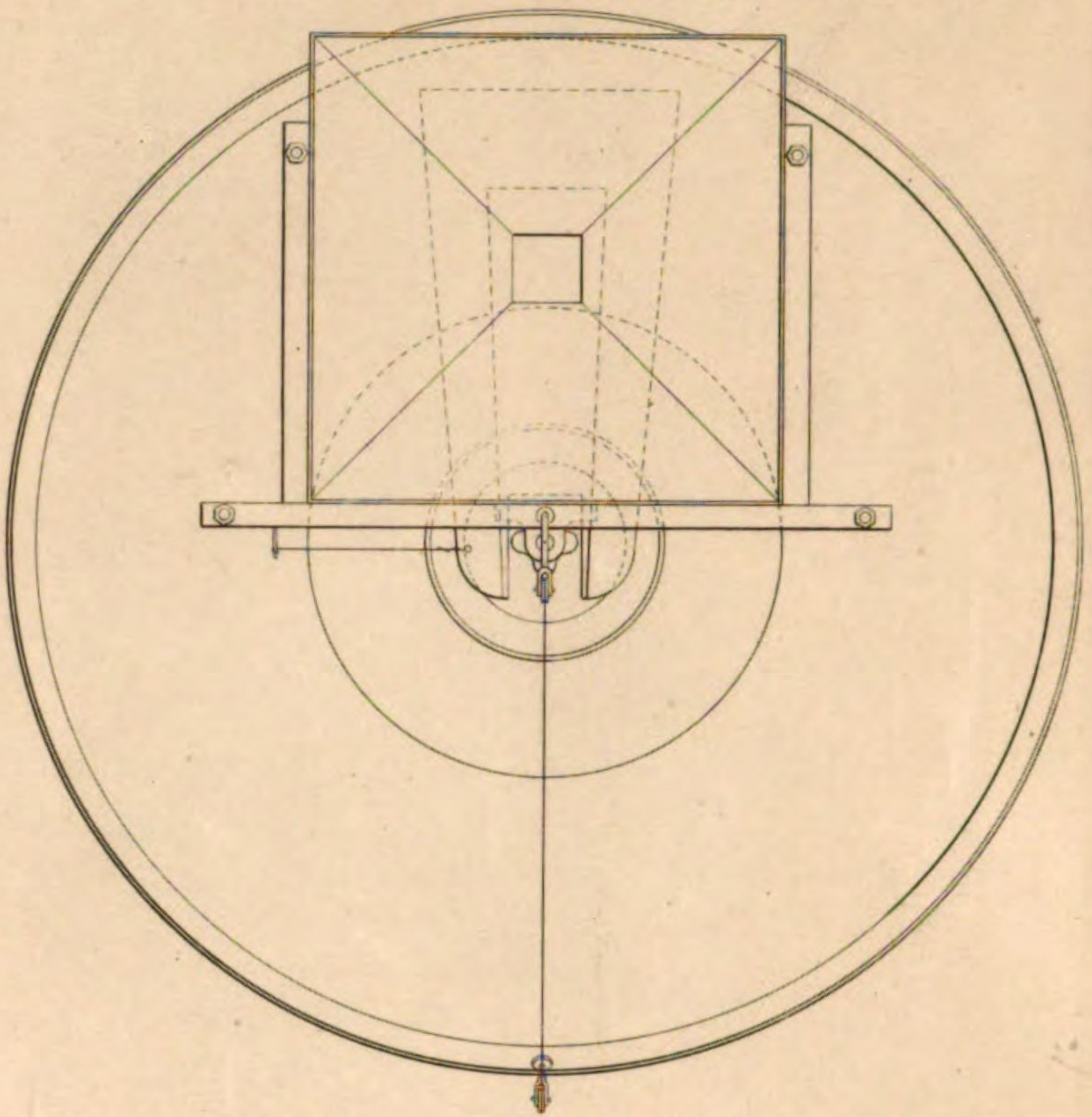
CONSTRUCTED BY
MESSRS W. JOYCE & CO GREENWICH NEAR LONDON.

J. W. Lowry sc.

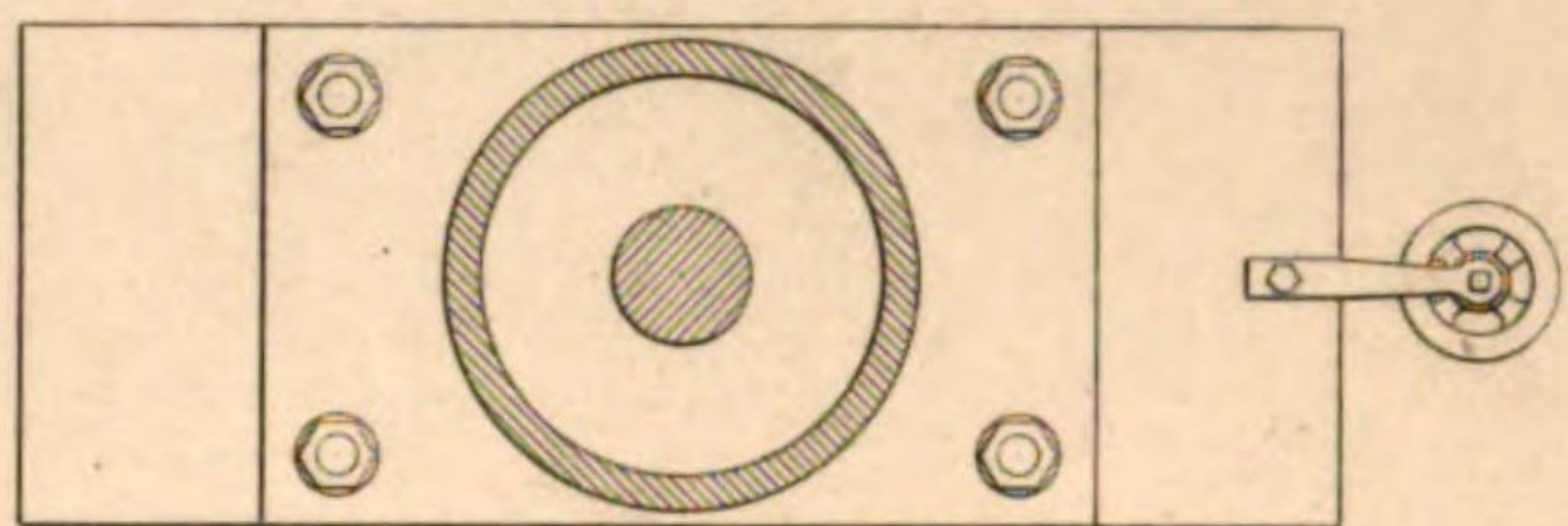




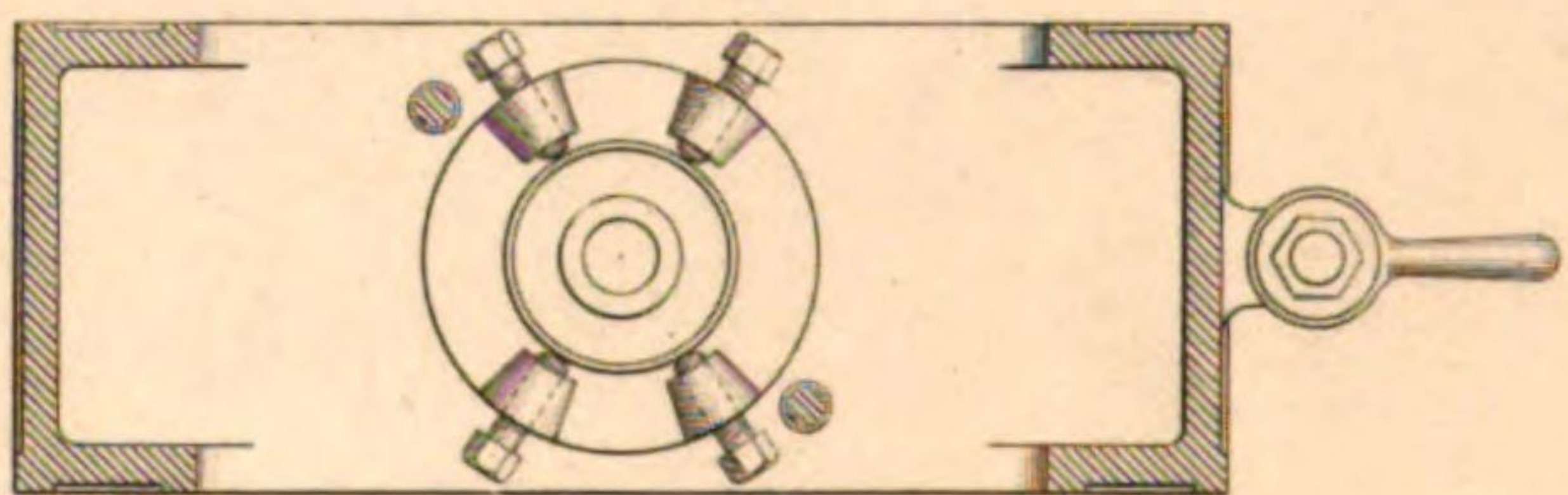
Plan of Hopper &c.



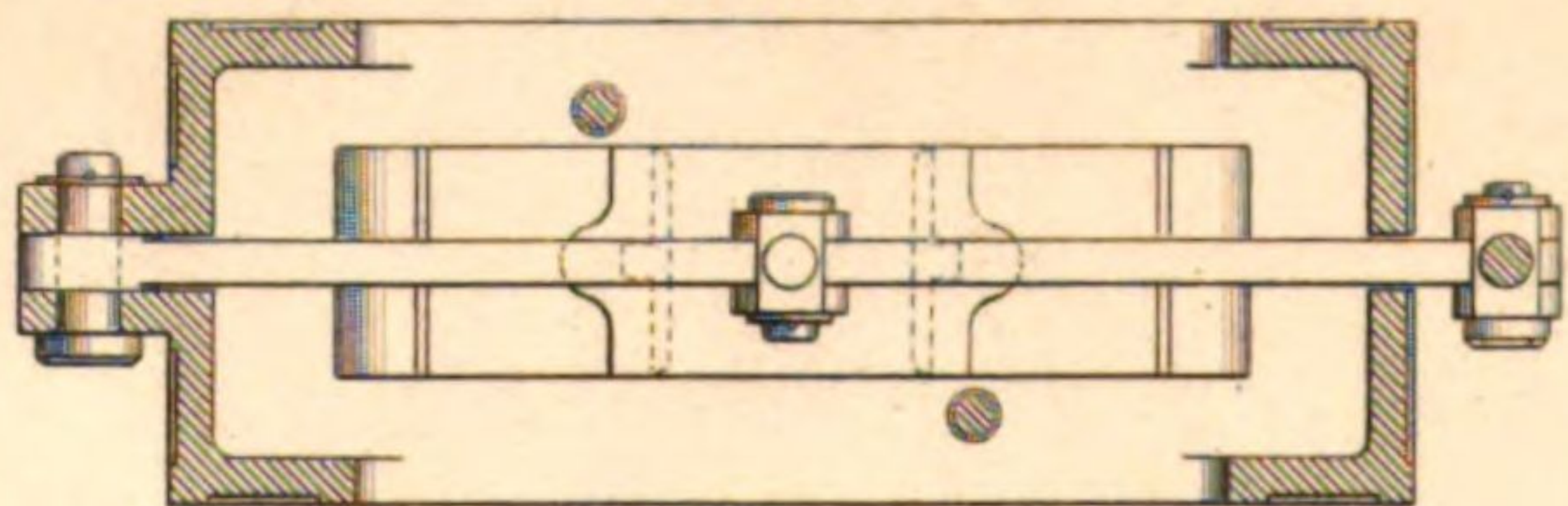
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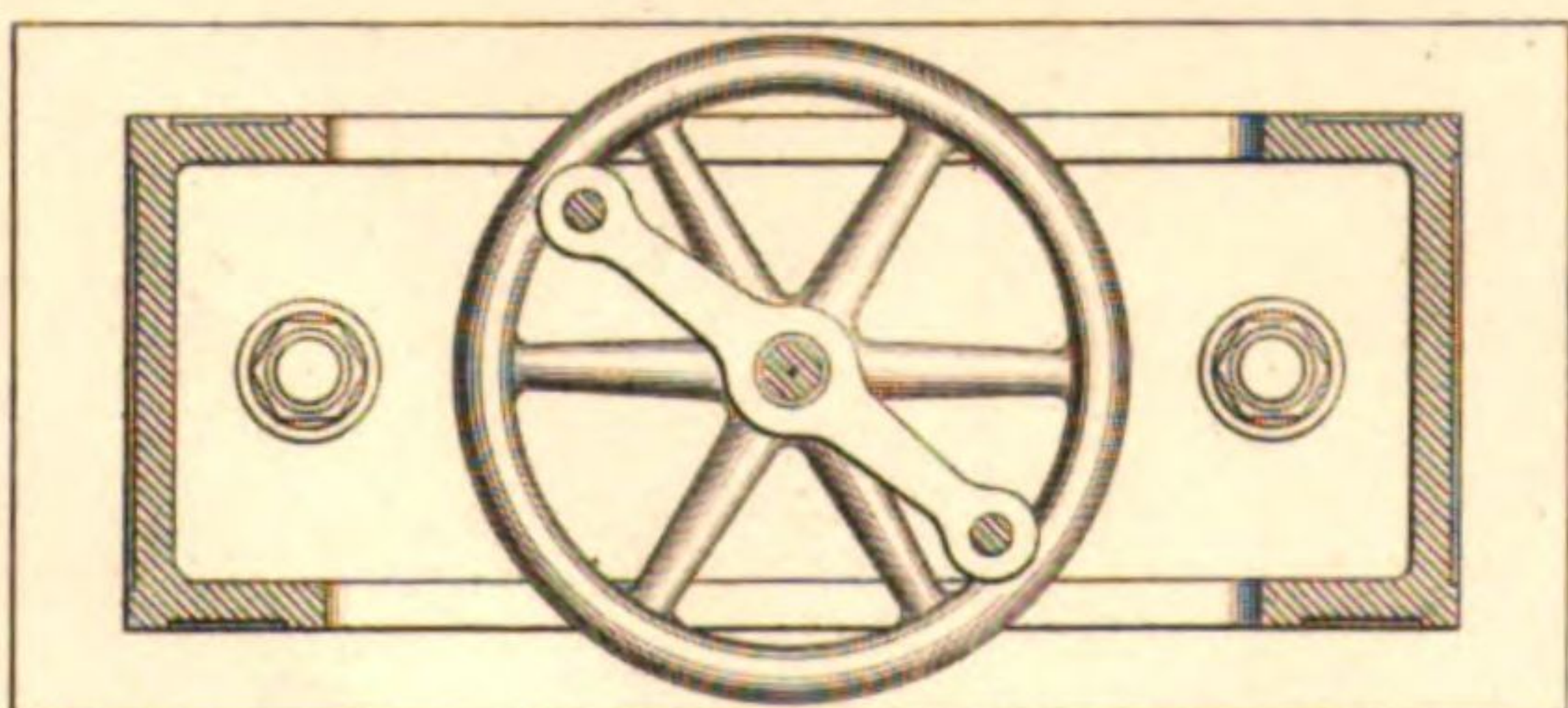
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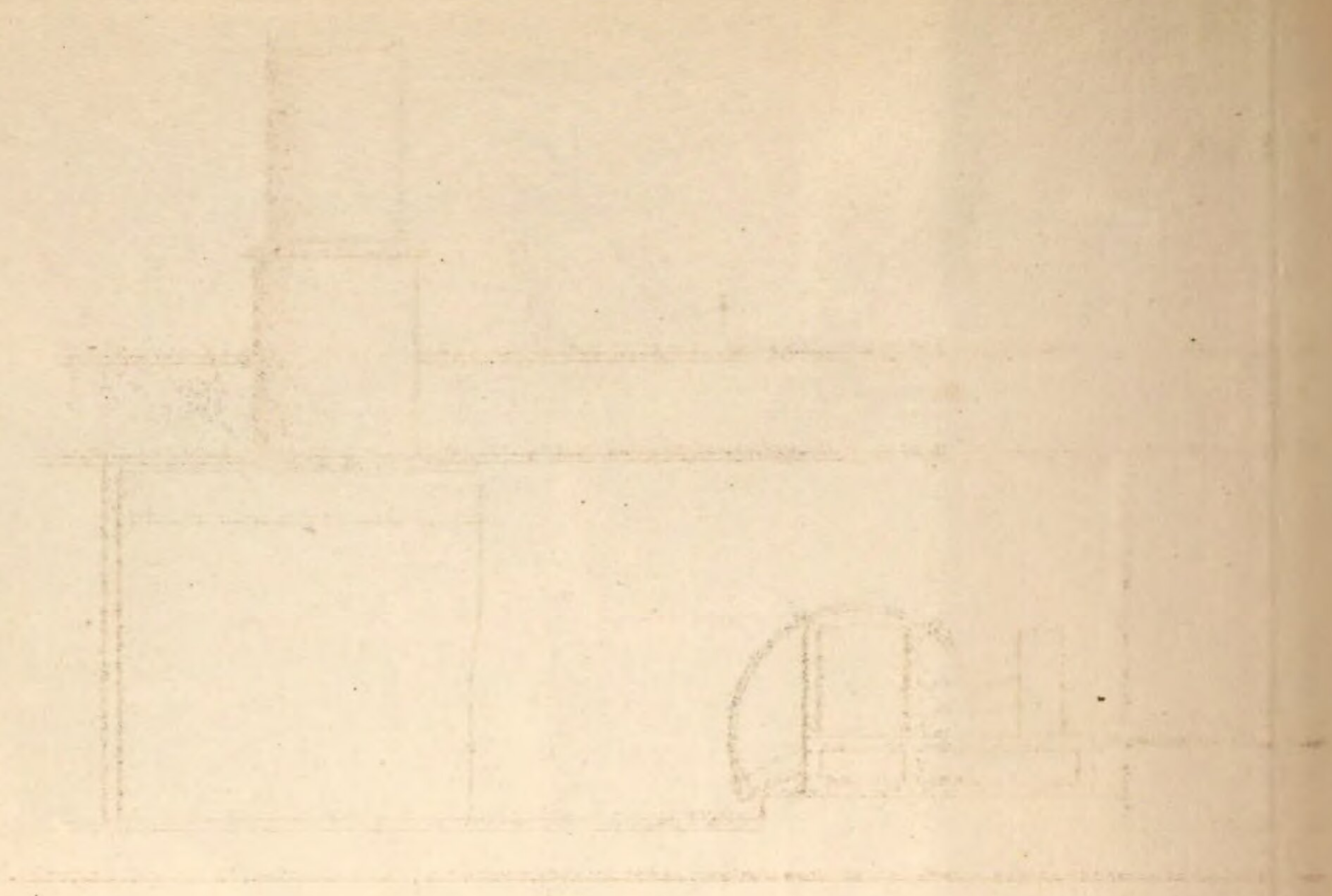


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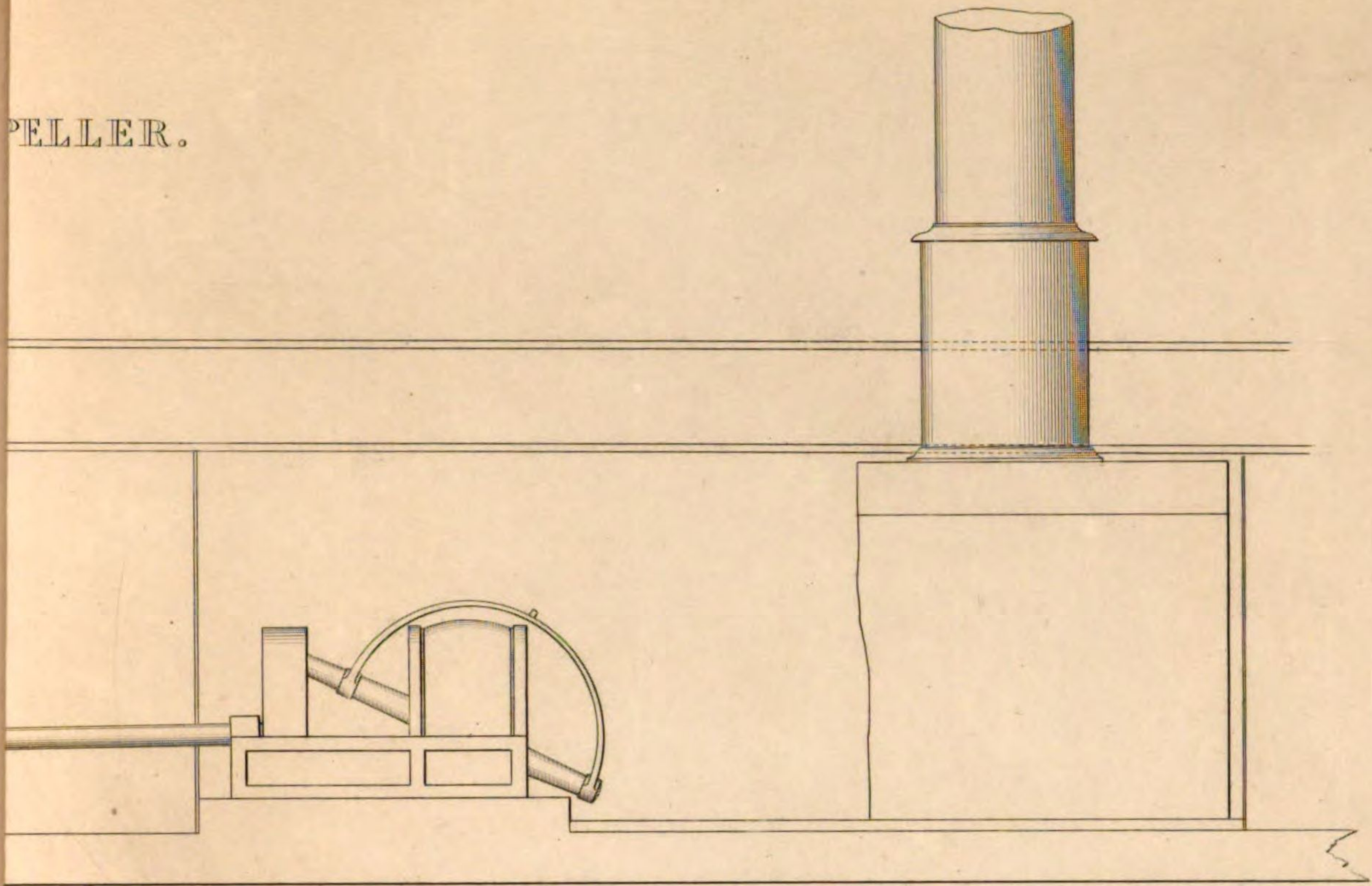


J.W. Lowry sc.

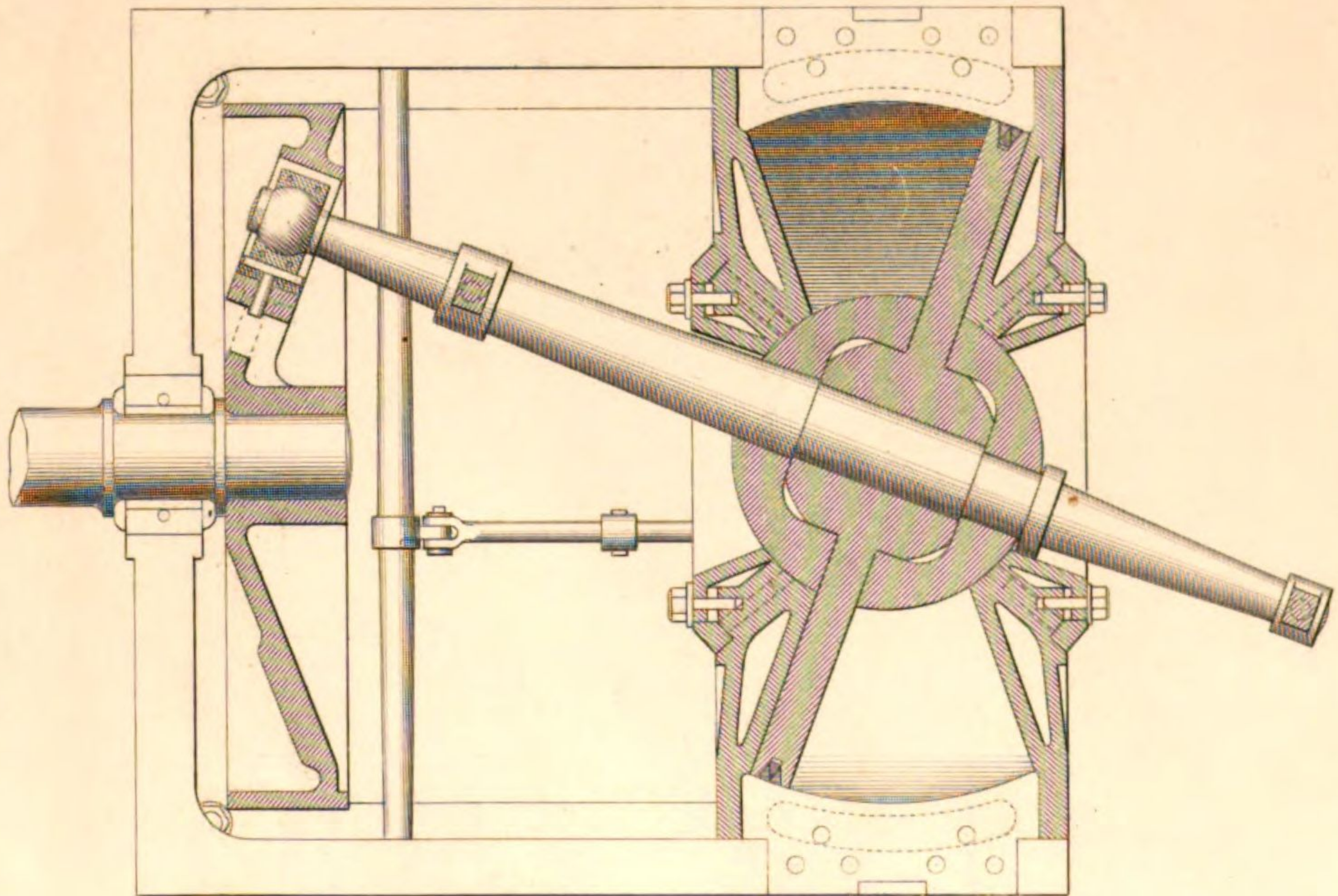
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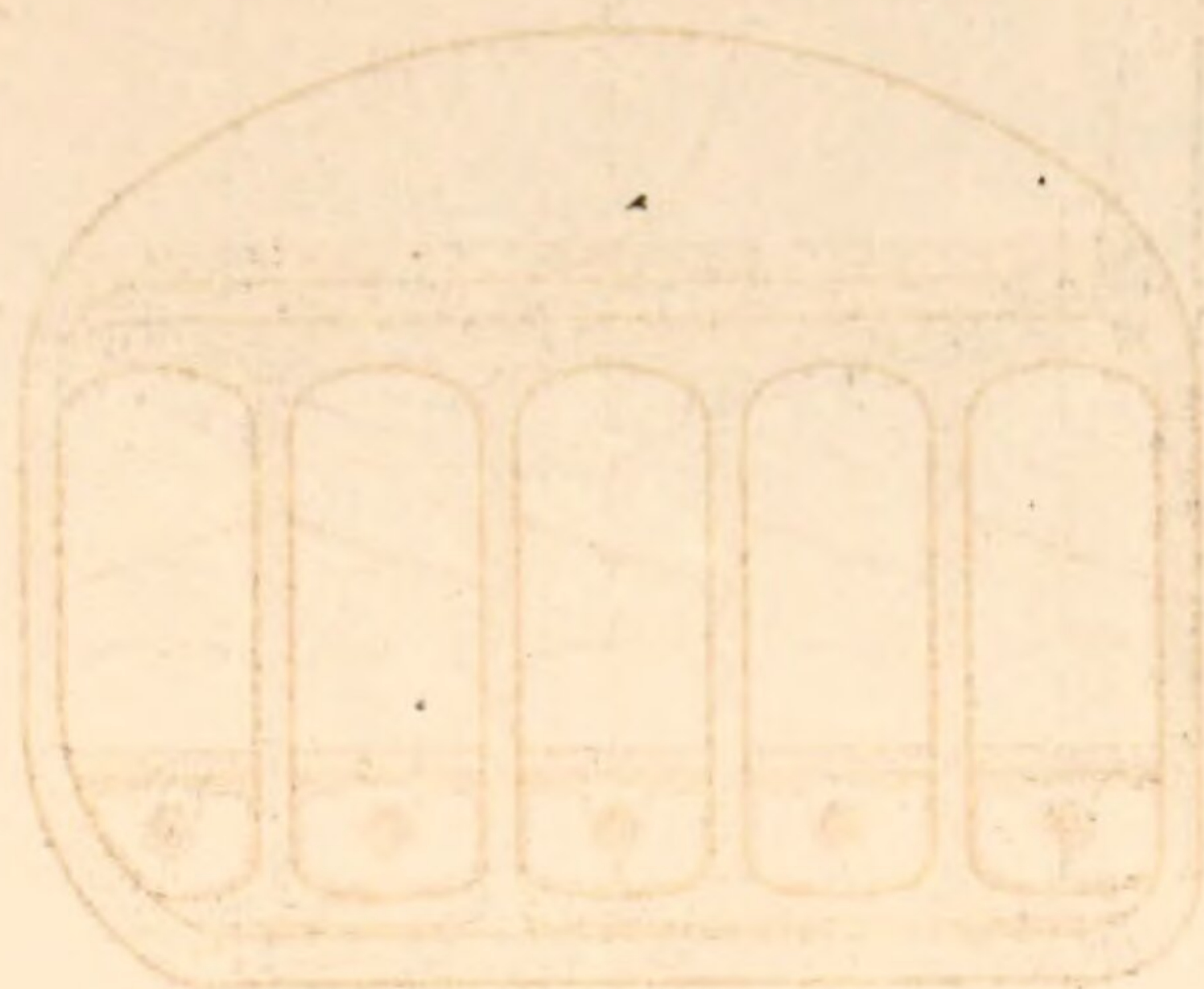
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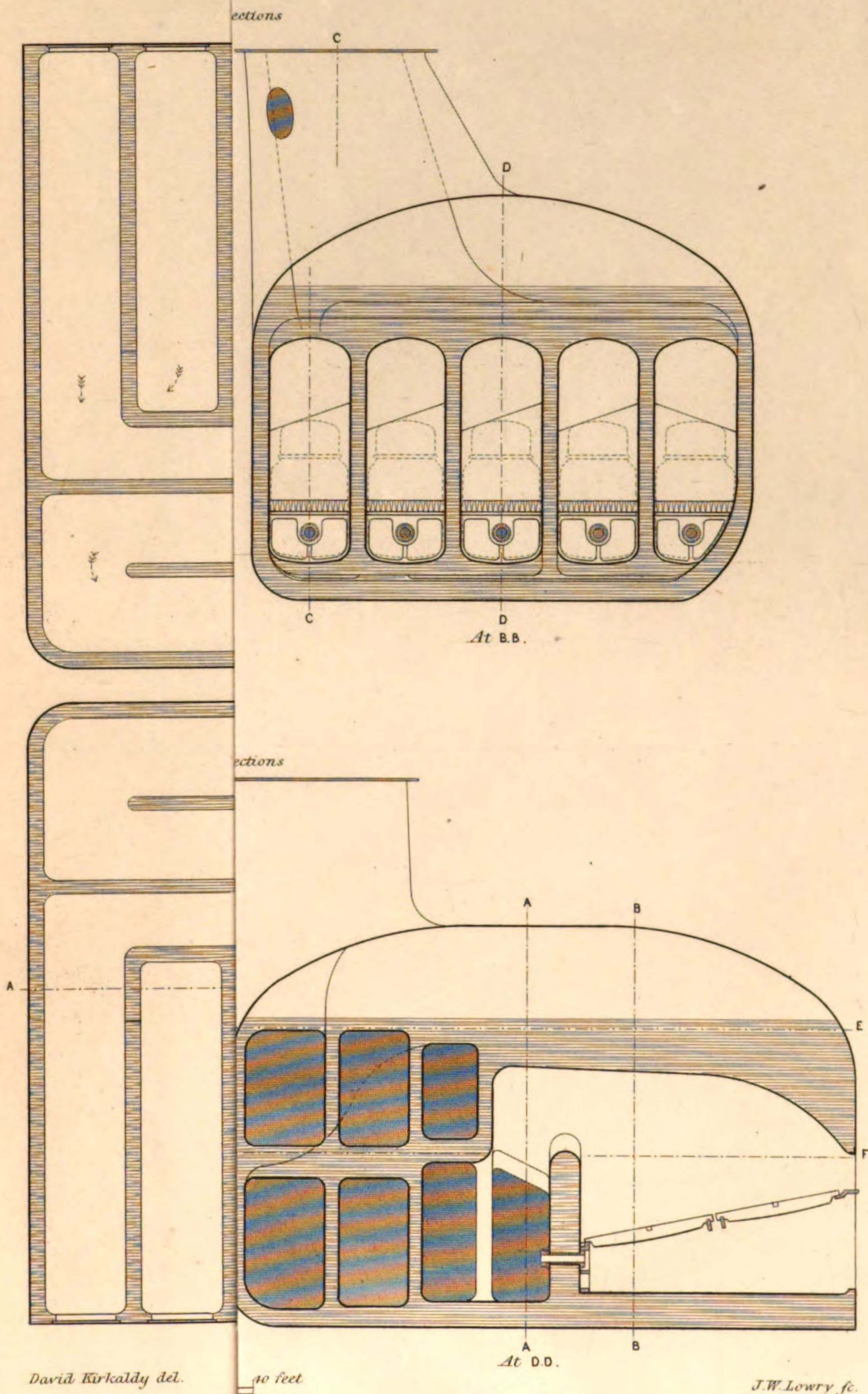


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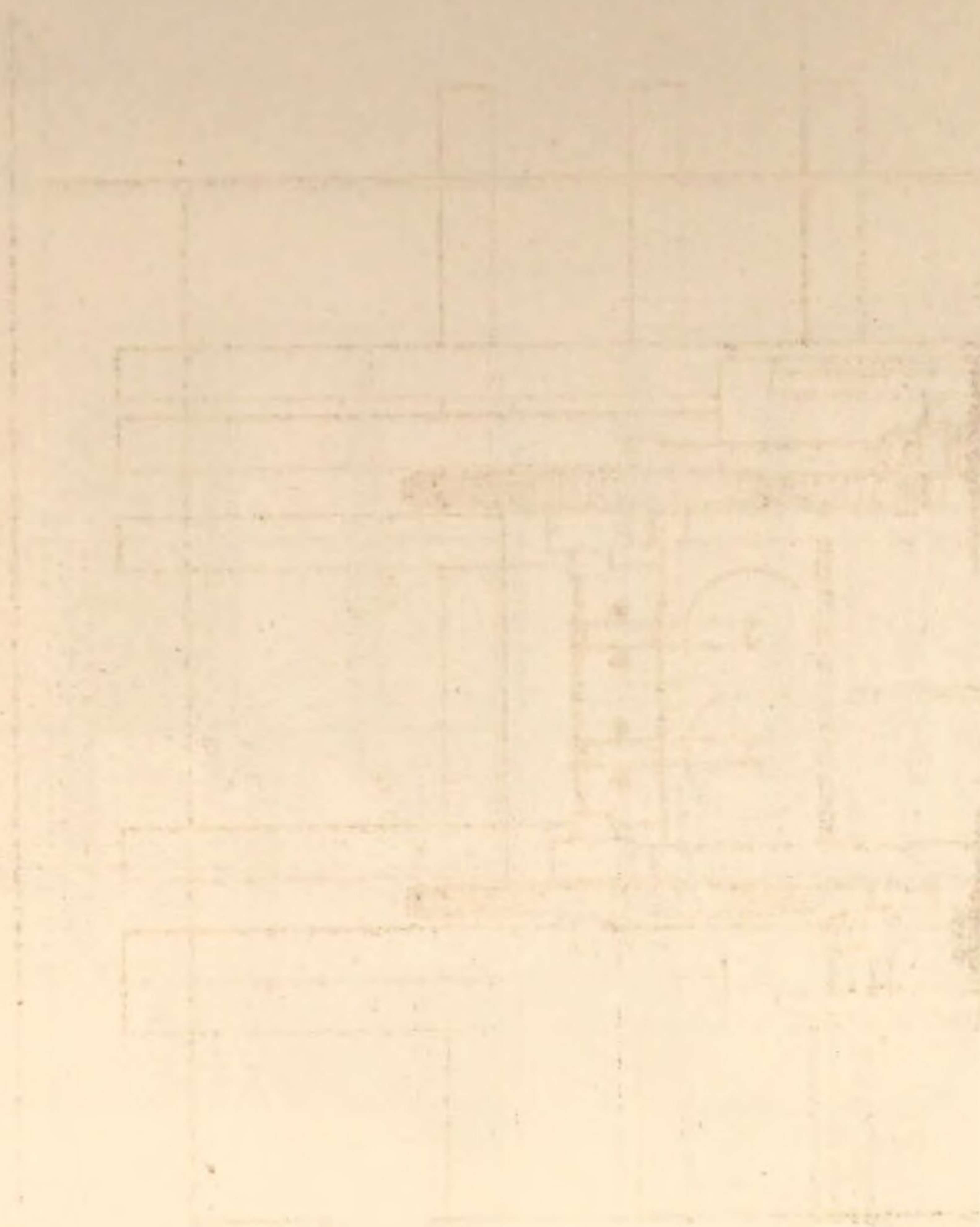


J. W. Lowry sc.





1870

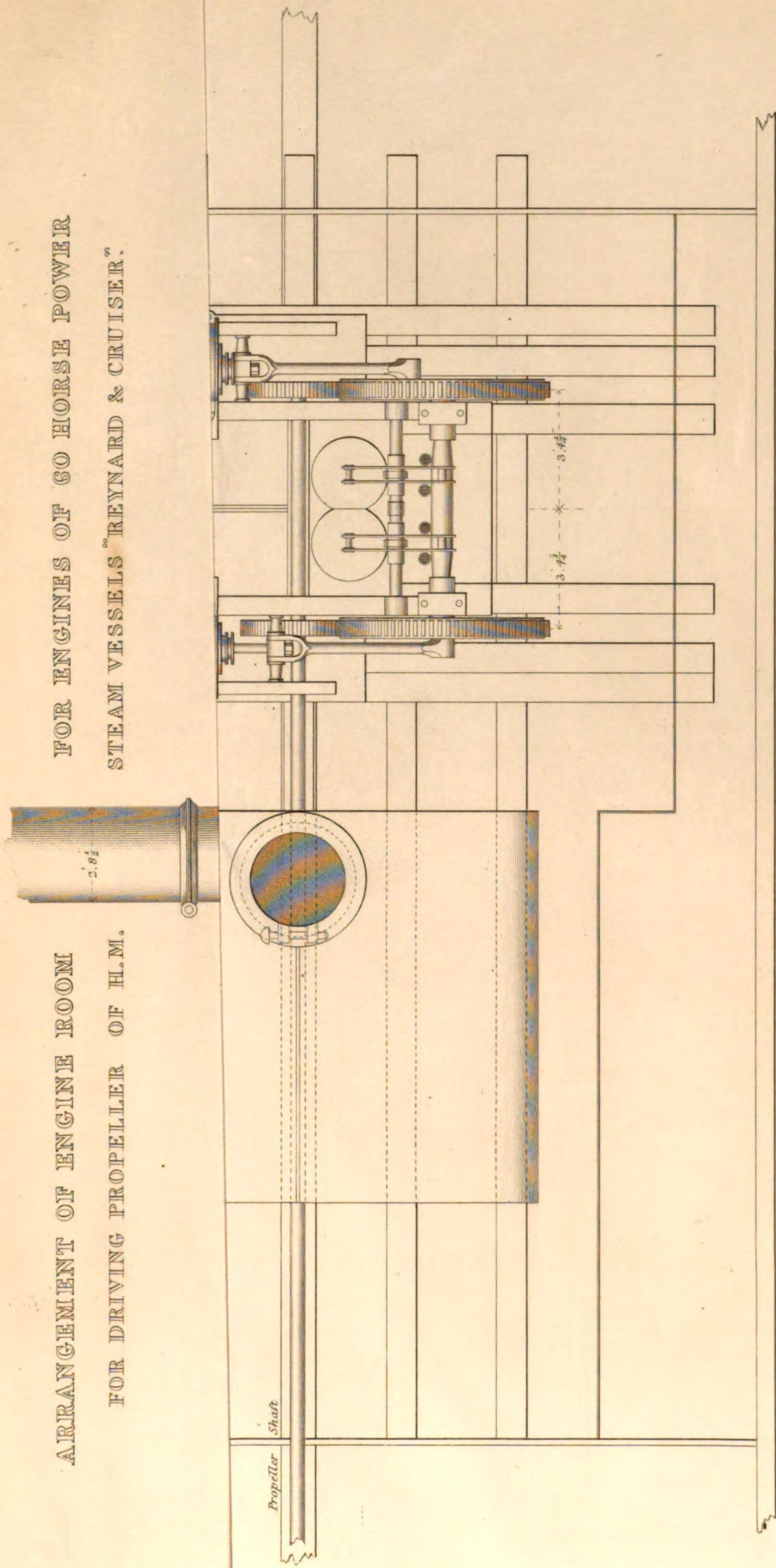


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1870

ARRANGEMENT OF ENGINE ROOM
FOR DRIVING PROPELLER OF H.M.

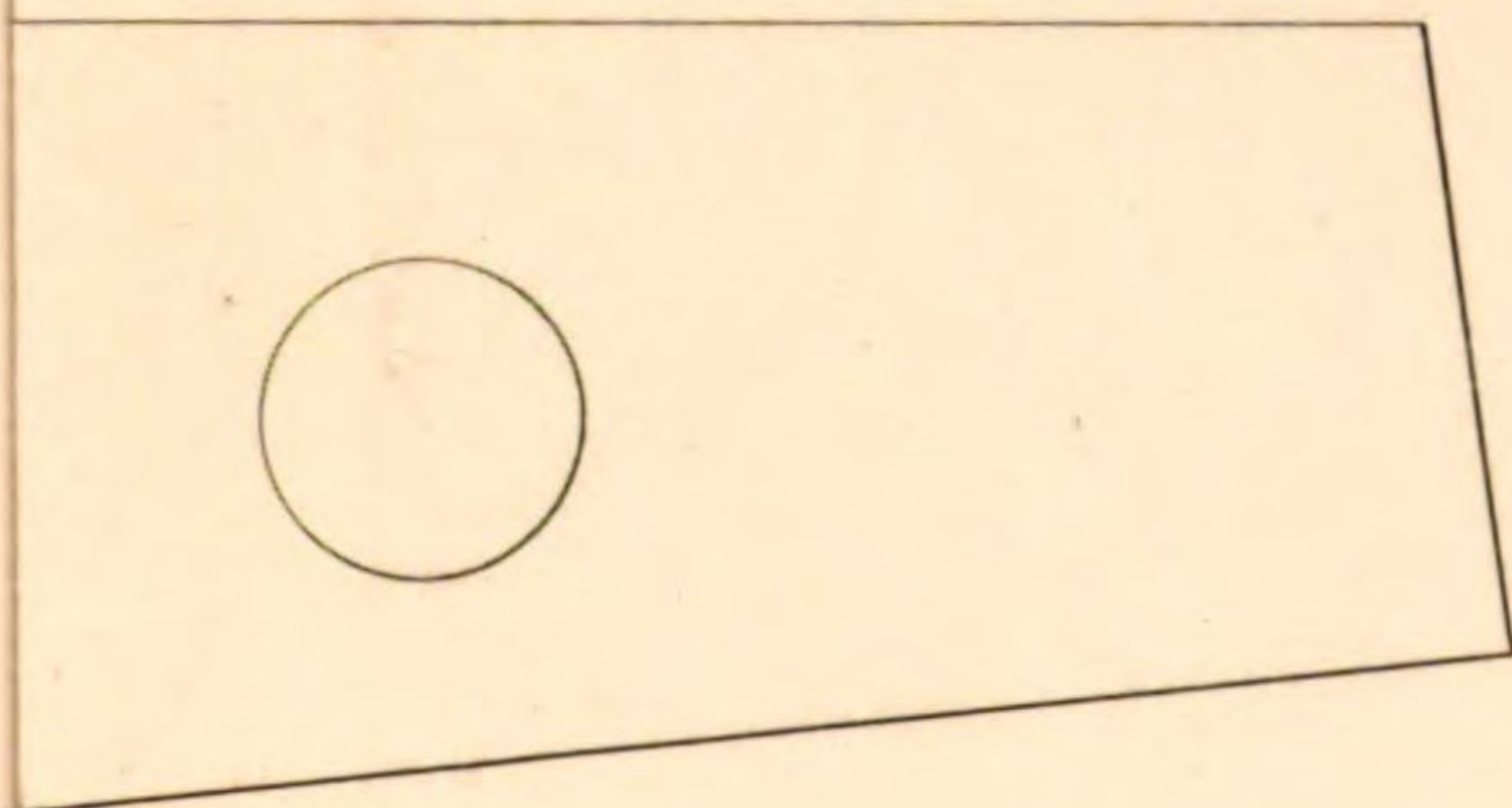
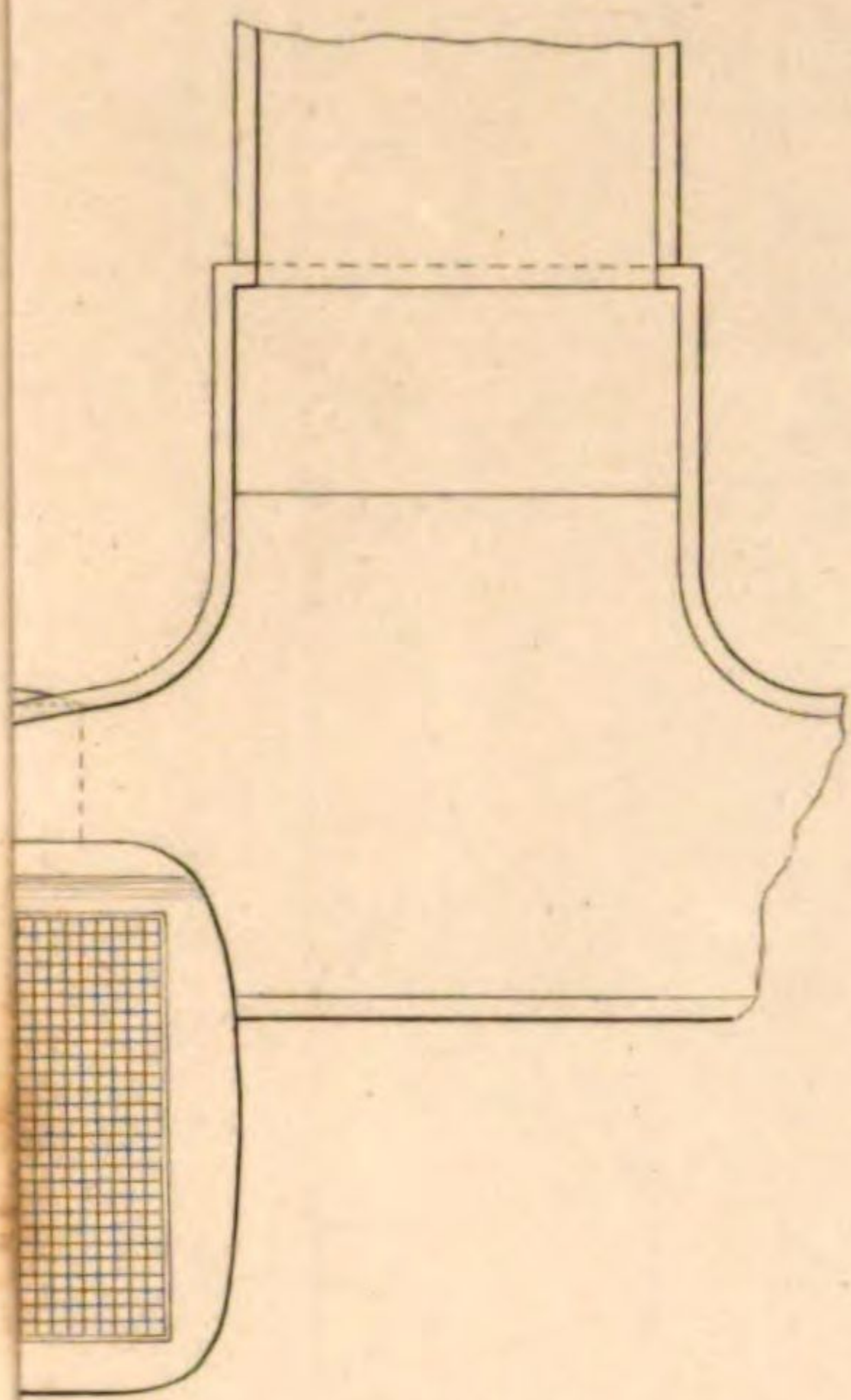
FOR ENGINES OF 60 HORSE POWER
STEAM VESSELS "REYNARD & CRUISER."



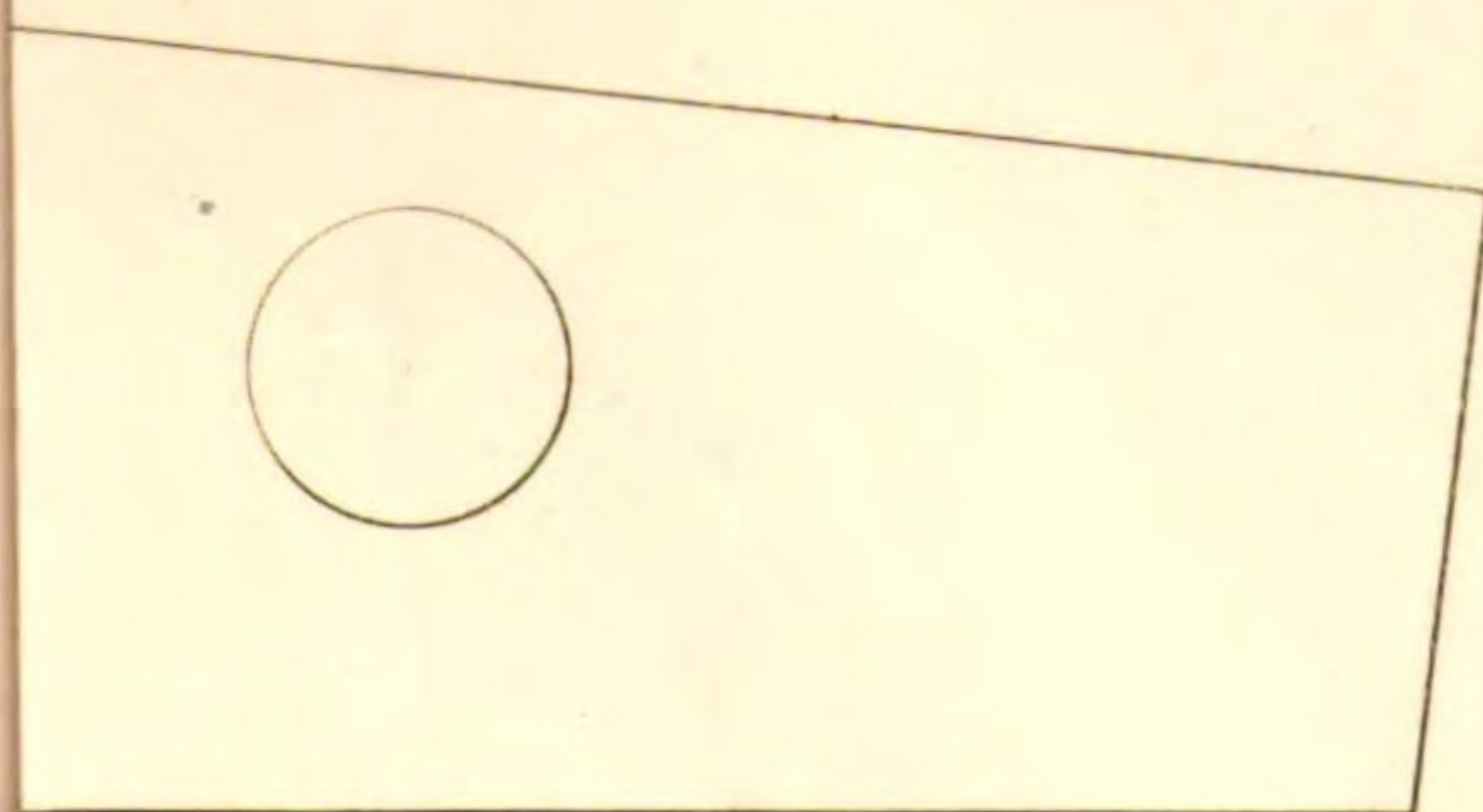
London. Published by John Weale, 59 High Holborn, July 1. 1852.

J. W. Lowry, sc.





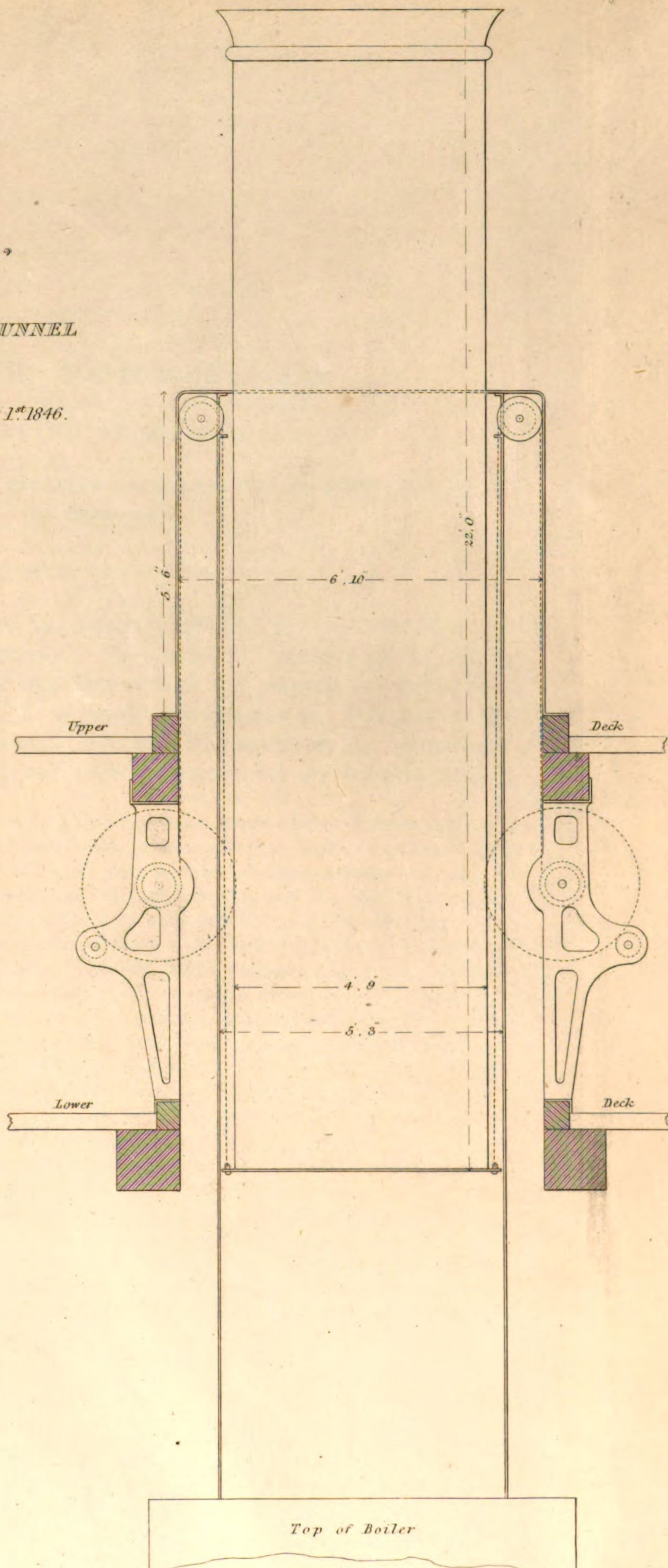
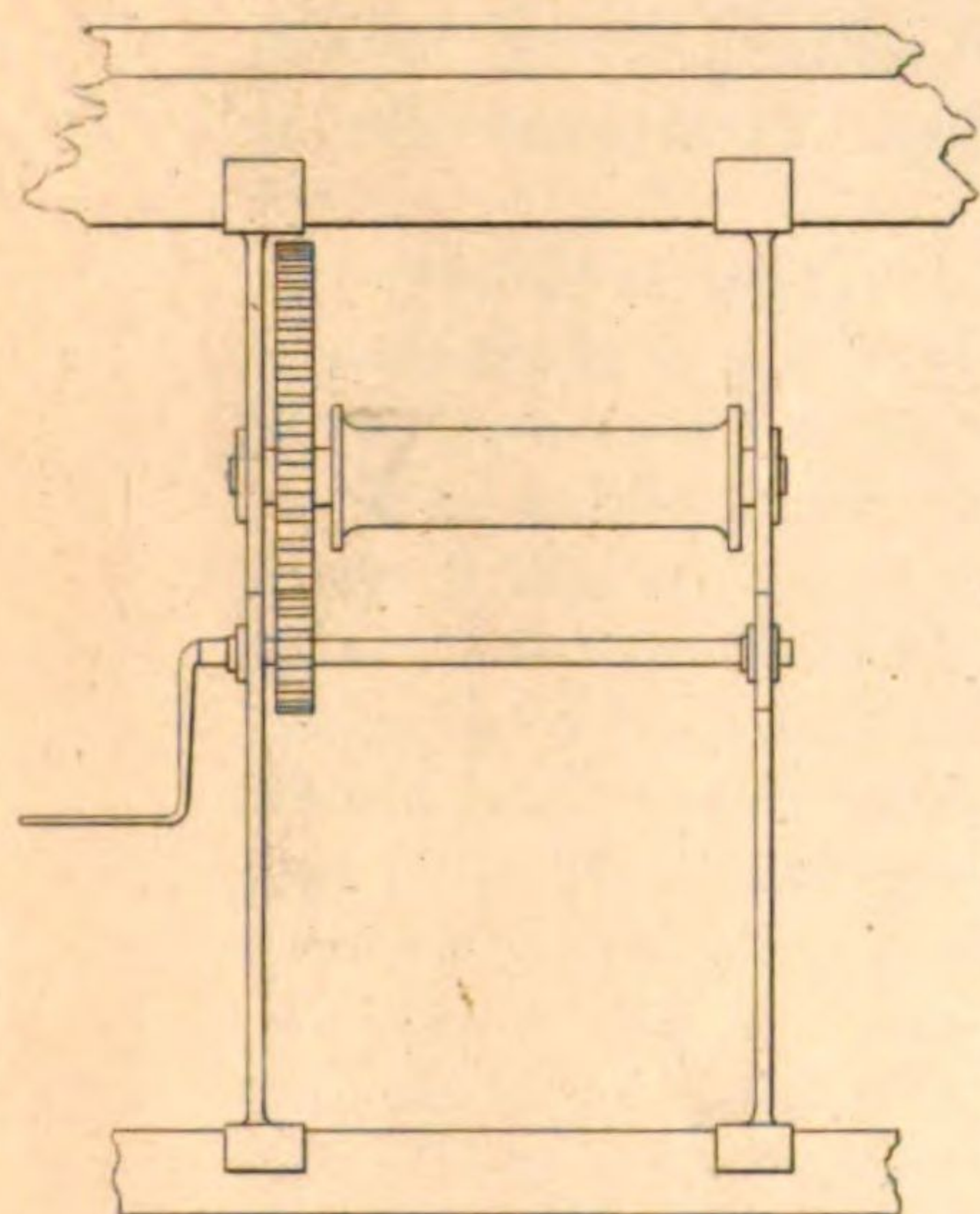
Plan



U.S. GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
BULLETIN 1034
WASHINGTON, D.C. 20506



H.M.S. SIDON,
 560 Horse Power
 PLAN OF TELESCOPE FUNNEL
 Scale $\frac{3}{8}$ " to a Foot
 Canal Iron Works Poplar May 1st 1846.



STEAM CORN-MILLS

ERECTED AT SMYRNA,

AND WORKED BY ENGINES RECENTLY CONSTRUCTED BY W. JOYCE AND CO.,
OF GREENWICH.

MILL MACHINERY, applied as the means of grinding of corn¹ into flour for human food, is of remote antiquity. The mechanical agencies of air, steam, and water have almost wholly been applicable to this purpose: up to the time of Smeaton, water-power was the principal agency employed; and even at the present time it is used in favourable districts. The machinery for water-wheels is still economical, and easily and readily adopted; but few improvements in

¹ "The end we have in view in grinding the grain is to reduce it to such a degree of fineness as is found by experience to fit it to make the best bread, and to put it in such a state that the flour may be most effectually separated from the bran, or skin of the grain, by means of sifting or bolting. It has been proved by experience, that to grind grain fine with dull mill-stones will not answer this purpose, because it kills or destroys that quality of the grain which causes it to ferment and raise in the baking; it also makes the meal so clammy that it sticks to the cloth, and chokes up the meshes in bolting; hence it appears that it should be made fine with as little pressure as possible, and it is evident that this cannot be done without sharp instruments. Let us suppose we undertake to operate on one single grain; it seems to accord with reason that we should first cut it into several pieces with a sharp instrument, to put it into a state suitable for being passed between two planes, in order to its being reduced to one regular degree of fineness. The planes should have on their faces a number of little sharp edges, to scrape off the meal from the bran, and should be set at such a distance apart as to reduce the meal to the required fineness, and no finer; so that no part can escape unground. The same rules or principles will apply to any quantity that will serve for one grain.

"To prepare the stones for grinding to the greatest perfection, we may conclude, therefore, that their faces must be put into such order that they will first cut the grain into several pieces, and then pass it between them in such a manner that none can escape without being ground to a certain degree of fineness, whilst at the same time it scrapes the meal off cleanly from the bran or skin.

"The best way that I have yet found to effect this is (after the stones are faced with the staff and pick) to grind between them a few quarts of fine sharp sand; this will face them to fit each other so exactly that no meal can pass them without being ground; this is also the best way of sharpening all

the water-wheel have been effected, and those principally by the Rennies,¹ Fairbairn, and Donkin.²

The overshot, the undershot, and the breast-wheel are still in use, some of which are of large diameter, and have good working and economical effect. Fairbairn's water-wheels with ventilated buckets have acquired much reputation,³ but steam-power for mill machinery is now almost universally adopted, and for this particular application much mechanical ingenuity has been exercised, and produced economy of labour, time, and money.

There are few persons who do not know that corn is ground by two mill-

the little edges on the face that are formed by the pores of the stone : instead of sand, water may be used, the stones then face each other ; they will then scrape the meal off the bran, without too much pressure being applied. But as the meal will not pass from the centre to the periphery or verge of the stones with sufficient rapidity without some assistance, there must be a number of furrows to aid it in its egress, and these furrows must be set with such a draught that the meal will not pass too far along them at once without passing over the land, or plane, lest it should get out unground. They should also be of sufficient depth to permit air enough to pass through the stones to carry out the heat generated by the friction of grinding ; but if they have too much draught they will not bear to be deep, or the meal will escape along them unground. These furrows ought to be made sharp at the feather edge, which is the hinder edge of the furrow and the foremost edge of the land ; this serves the purpose of cutting down the grain : they should be more numerous near the centre, because there the office of the stone is to cut the grain, and near the periphery the office of the two planes is to reduce the flour to the required fineness, and scrape the bran clean, which is effected by the edges formed by the numerous little pores with which the burr-stone abounds. We must consider, however, that it is not best to have the stones too sharp near the eye, because they then cut the bran too fine. The stones incline to keep open near the eye, unless they be too close. If they be porous (near the eye) and will keep open without picking, they will remain a little dull, which will flatten the bran, without cutting it too much ; but if they be soft next the eye, they will keep too open, and that part of the stone will be nearly useless ; they should therefore be very hard and porous.

"It is also necessary that the face of the stone be dressed in such a form as to allow room for the grain or meal in every stage of its passage between the stones. In order to understand this, let us conceive the stream of wheat entering the eye of the stone to be about the thickness of a man's finger, but instantly spreading every way over the whole face of the stone ; this stream must therefore get thinner as it approaches the periphery, where it would be thinner than a fine hair, if it did not pass slower as it becomes finer, and if the stones were not kept apart by the bran : for this reason the stones must be so dressed that they will not touch at the centre within about a 16th or 20th part of an inch, but get closer gradually, till within about 10 or 12 inches from the verge of the stone, proportioned to the diameter, and from that part out they must fit nicely together. This close part is called the flouting of the stone. The furrows should be deep near the centre, to admit wheat in its chopped state, and also the air, which tends to keep the stones cool."—*Oliver Evans's 'Young Mill-wright and Miller's Guide,' by Jones, Philadelphia, 1850.*

¹ Weale's 'Papers on Engineering,' vol. iv. 4to.

² Templeton's 'Workshop Companion,' 24mo, p. 137.

³ Fairbairn on Water-wheels, 4to, 1849.

stones placed one above the other, without being in contact: the lower mill-stone is a fixture, while the upper one turns upon a spindle.¹

The opposite surfaces of the two stones which act to grind the corn have channels or furrows cut in them, proceeding obliquely from the centre towards the circumference, and these furrows are each cut perpendicularly on one side and obliquely on the other into the stone, which gives each furrow a sharp edge, and are so arranged that in the two stones, when the mill is in motion, the above-named edges come against each other after the manner of a pair of scissors, and so cut the grain, which causes it to grind the easier when it comes upon the spaces between the furrows.

When the furrows become blunt and shallow from wearing, the running stone must be taken up, and both stones dressed anew.²

Among the Engineers who have turned their attention to steam flour-mills few occupy a more distinguished position, or have a larger practice in the construction of such and similar machinery, than Messrs. Wm. Joyce and Co., of the Greenwich Iron-Works, whose double-cylinder direct-acting engines and corn-mills are to be found not only in nearly all parts of Great Britain, but on the Continent of Europe.

The example we have chosen as the subject of our present illustration is a large corn-mill of fourteen pairs of stones, put in motion by a pair of double-cylinder direct-acting engines of the nominal collective power of 50 horses, and perhaps the importance of the application of steam-power to mill machinery has never been more strongly developed than in the case to which, on the present occasion, we have to direct the attention of our scientific readers.

The construction of steam machinery in England, and its erection at Smyrna for the purpose of grinding corn, and thereby rendering that district independent of flour imported from other parts, is a matter of some importance, and has excited much attention; we have therefore obtained the following information on the subject.

It would appear that in Smyrna, up to the time of the formation of the Smyrna Steam Flour-Mill Company, the whole of the mills were worked by

¹ The diameter of the mill-stones most in use at the present day is 4 feet, and their thickness about 12 inches; one-half of this thickness is composed of French burr, a hard though porous mineral, of a silicious nature; the other half is made of plaster of Paris. Mr. Frederick Ransome, Flint Wharf, Ipswich, has been successful in the application of his patent stone for this purpose.

² The burr-stones usually occur in beds, which are sometimes continuous, and at others interrupted. These beds are placed amidst deposits of sand, argillaceous and ferruginous marls, which penetrate between them, filling their fissures and honeycomb cavities. Burr-stones constitute a very rare geological formation, being found in abundance only in the mineral basin of Paris and a few adjoining districts.

horse and wind power, which was found to be totally inadequate to meet the demands of local consumption; the natural consequence being the importation of flour to a great extent from other parts, and rendering its cost excessive. To counteract these effects, the present Company has been formed, the Turkish Government having granted its especial patronage, with an exclusive privilege for fifteen years, and the right to supply the troops and navy of the Sultan during that period: the result has shown that the expense of grinding by steam is less than half the cost under the old system, and six times the quantity can be done in a given time.

The advantages of a Company with capital and the most improved machinery enables the public to obtain a better article at a reduced rate, at the same time yielding large profits to the shareholders.

The capital has been fixed at £22,750, divided into 1000 shares of £22 15s. each, of which £12,750 was required for the purchase of land, erection of buildings, cost of machinery, and other requisites for immediately prosecuting the operations of the Company, the remaining £10,000 being the working capital.

To effect the object in view, two double-cylinder engines, with boilers, gearing, &c., have been constructed by Messrs. William Joyce and Co., of the Greenwich Iron-Works, the cost of which was estimated at £6000; while that of land, buildings, freighting, and other incidental expenses, amounted to £6750—thus leaving, as before stated, £10,000 as a floating capital.

Annual expenditure and returns may be thus given: Cost of 360,000 bushels of wheat, being the quantity consumed or ground in 300 days, £58,909; added to which must be taken the estimated annual charges, including commissions, &c., £6227, making together £65,136, while the returns for such period, at a reduced rate from that now charged, and making every allowance, would yield, after allowing all charges (including reserved fund), a net revenue of £6736 per annum, or 30 per cent. on the capital employed: fourteen pairs of stones, with the attendant machinery, have been sent out and erected, twelve pairs of which are kept constantly at work, and yield the returns previously stated.

The engines which Messrs. Joyce have constructed for this purpose have been formed upon a principle which was entirely new in this country, until Mr. William Joyce turned his attention to the improvement of double-cylinder engines, and designed his *now* celebrated pendulous direct-acting high and low pressure condensing engines, with two cylinders, which have been found to work with such unexampled success in all the establishments in which they have been adopted.

In their general arrangement they may be described as belonging to the class of

engines termed 'oscillating,' from the circumstance of their cylinders vibrating on axes or trunnions, in order that the piston-rods may constantly act upon the cranks without the intervention of the beam, parallel motion, connecting rods, &c., &c.,—contrivances by which, in most stationary engines, the vertical motion of the piston-rod is adapted to the circular motion of the crank. The great principle, discovered by Woolf¹ nearly half a century ago,² of introducing steam of a high pressure into a small cylinder, and allowing it to act expansively in a larger one at a less pressure than the original, in proportion to the areas of the cylinders respectively, and afterwards to add to its effective force by condensation, is here applied in an extremely ingenious manner, and with a simplicity of arrangement having reference to the multiplicity of objects which are to be provided for simultaneously in the machine. What Woolf did by the intervention of parts which rendered the action indirect, is here done without the aid of such subsidiary arrangements, and the action is **DIRECT**: the cylinders are for this purpose inverted, and vibrate upon the steamways at their upper extremities; the horizontal shaft (on which the great spur fly-wheel is fixed) is furnished with cranks at right angles, so that the dead point is always got over, and the motion is transmitted from the spur fly-wheel to the wheel on the long laying shaft of the fourteen mills, each of which is furnished with a pair of French burr-stones for grinding wheat. The construction of the steam engines will be readily understood by inspection of Plates I. and II., which show the engines in elevation, end view, section and plan; and it may be here remarked that the average consumption of fuel by Messrs. Joyce's improved pendulous engines does not exceed 3 lbs. per horse-power per hour, and their extreme simplicity renders them less expensive in their first cost, and less liable to derangement, than any other form of double-cylinder engine now in use.

Plate III. is a section of the mill, taken in the direction of its length, and exhibits the elevation of the mills and driving gear, and also shows in elevation the whole of the internal arrangements and machinery.

Plate IV. is a plan of the mill, taken in a horizontal line at the stone floor, and also shows a plan of the foundations of the engines, and the plan and arrangement of the four boilers, their flues, chimney, &c.

¹ Woolf's patent steam engine for an experiment made before seventeen of the principal engineers of 1811. See Weale's 'Papers on Engineering,' vol. iii. 4to, 1845.

² This form of engine was invented by Mr. Arthur Woolf, and patented by him in the year 1804. The peculiarity in its mode of action consists in employing two cylinders, through both of which the same steam is made successively to pass. The details of its construction will be better understood by reference to Gregory's 'Mathematics for Practical Men,' 8vo, 1848.

Plate V. is a transverse section of the mill and engine-house, showing the relative position of the steam engines and mill; and it also shows the position of the dressing machines, sack tackles, elevations, and the shafting for driving the same.

Plate VI. is an elevation and section of the four Cornish boilers, showing the principle on which they are set, the disposition of the flues, the fittings, mountings, and connections of the boilers.

Plate VII. shows the details of the mill-work, being in fact a working drawing of one of the mills.

GENERAL DESCRIPTION.

The house in which the steam engines and mill are set up is built of the white stone of the country, and is of great strength and solidity; it consists, as is usual in mills of this magnitude, of five floors, besides the ground-floor. By reference to Plates IV. and V. it will be seen that the engines and boilers, although in the same building, are quite distinct and separate from the mill, so that all chance of fire is avoided. The fly-wheel of the engines is termed a 'spur fly-wheel' from the external part of the rim being cast with teeth, and thus performing the double purpose of a reservoir of the power of the engines, and the means of transmitting that power to set the mill in motion.

The spur fly-wheel is of 16 feet diameter at the pitch line, makes 25 revolutions per minute, and gears with the pinion on the laying shaft of the mill: it is 6 feet 6 inches in diameter at the pitch line, and makes 61 revolutions per minute. The mortise bevel-wheels on this shaft are 3 feet 7 inches in diameter, driving the bevel pinions on the mill spindles of 1 foot 10½ inches in diameter;—consequently the mill-stones are driven at the rate of 117 revolutions per minute.

The corn to be ground is brought to the mill in sacks on camels, and it is hoisted by sack tackles to the upper floor of the mill, and shot into the centre garner, which is situated directly over the corn-screening machine, or 'smutter,' as it is commonly called, where it is cleaned from blight, dirt, and other matters that are always more or less found in wheat.

This machine is a large cylindrical sieve, formed of wire and furnished with beaters inside, made of cane, and mounted on an axis to agitate the wheat: this revolves with much velocity in a close case, in which it is set at an angle. The corn descends from the garner and enters the upper end of the screening machine, and having been well agitated in its passage through the interior of the machine, and thereby set free from the dirt with which it was mixed, falls into an inclined trough

at the lower end, which conducts it to the elevator; and in its passage through this trough or spout it is acted upon by a blast of air from a circular fan, in order to carry off such dust or other light particles as may escape with the grain from the smut machine.

The grain having gone through the operation of cleaning, is then raised by the elevator and delivered into a box situated on the top floor of the mill, from which it falls through inclined troughs into two wheat-bins which are situated directly over the mill-stones, and from each of these bins seven pairs of stones are supplied with the wheat to be ground, through the feeding pipes into the hoppers, one of which is provided on the top of each mill; and the wheat having been reduced to meal by its passage between the stones, it falls through suitable pipes into the creeper boxes, from which it is transferred to the meal elevators, and raised by them to the top of the house, and shot over into the meal-bins over the dressing machines: after it has passed through the dressing machine, and has become fine flour, it is stored away till required for delivery or use.

The dressing machine is somewhat like the screening or smut machine already described; it consists of a cylinder at an angle, of wire gauze of different degrees of fineness: within this cylinder, circular brushes revolve in contact with the wire cloth, and the flour which is admitted into this cylinder at the upper end is by the motion of the brushes sifted or brushed through the wires. The finest flour is delivered through the finest wire at the upper end of the machine; the second quality, as regards fineness, through the next finest wires, and so on, according to the number of qualities required, until the refuse or bran is discharged through the cylinder at its lower end.

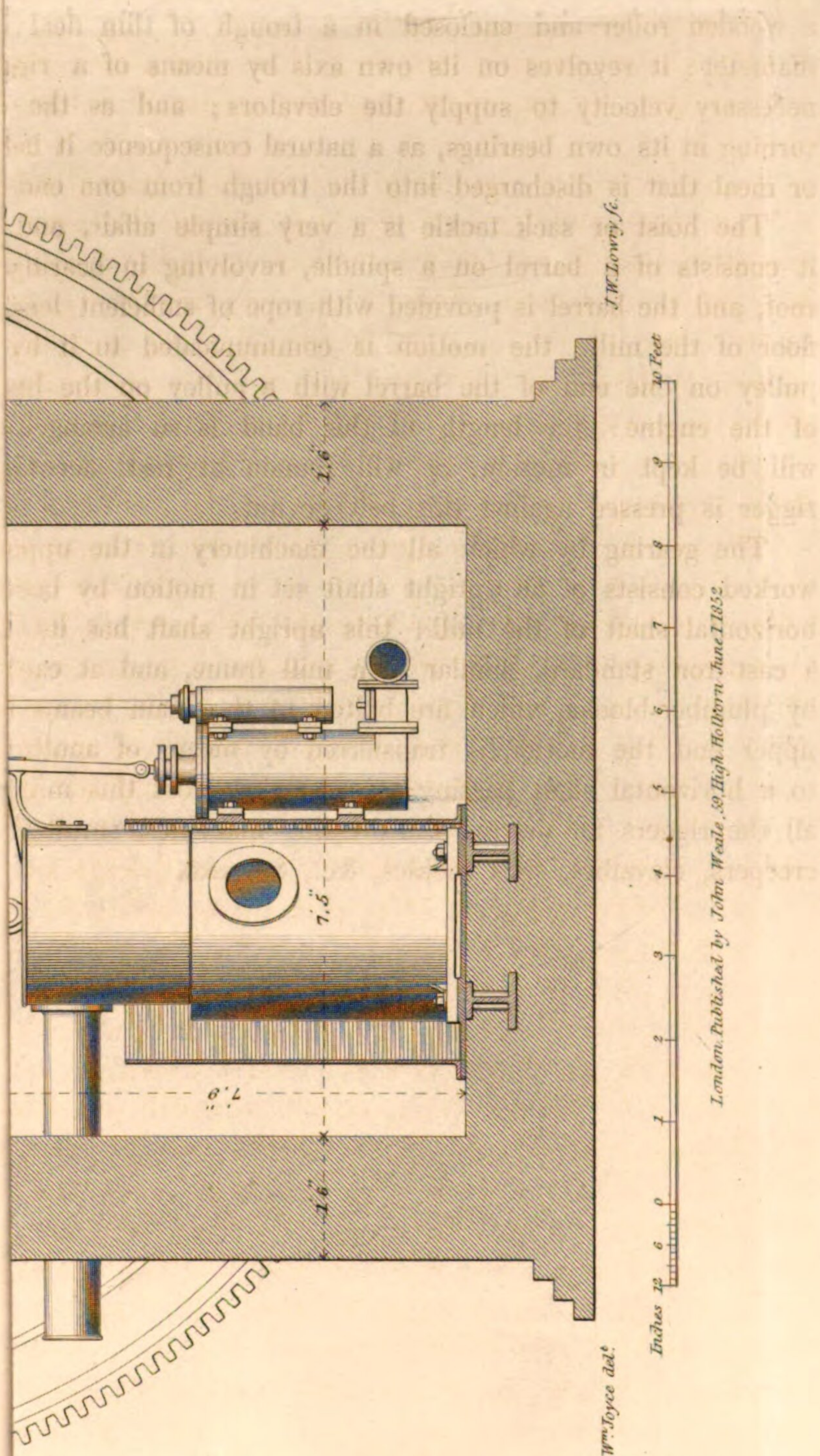
The elevator is a long endless leather band or canvas web, with small buckets made of tin, fixed to it at equal distances, the leather or canvas band passing over two iron riggers, each enclosed in a cast-iron box or frame. The uppermost of these pulleys is driven at the necessary velocity by a band, and the tin buckets passing the opening through which the grain is discharged from the smutter one after the other, they each take a portion of it, which they carry up through the wooden trunks through which they work to the upper floor of the mill, where the wheat is delivered into the box, and through the spouts into the wheat-bins. The machine above described, and which is termed an 'elevator,' is applicable to the raising grain or meal from a lower floor to a higher floor; but for conveying meal, wheat, or flour in a horizontal direction, an apparatus called a 'creeper' is used, which is a very simple application of the ancient principle of the Archimedean screw to economize human labour. The creeper is an endless screw with a very wide pitch and very thin threads, constructed in many cases only of a strip of sheet tin, wound round

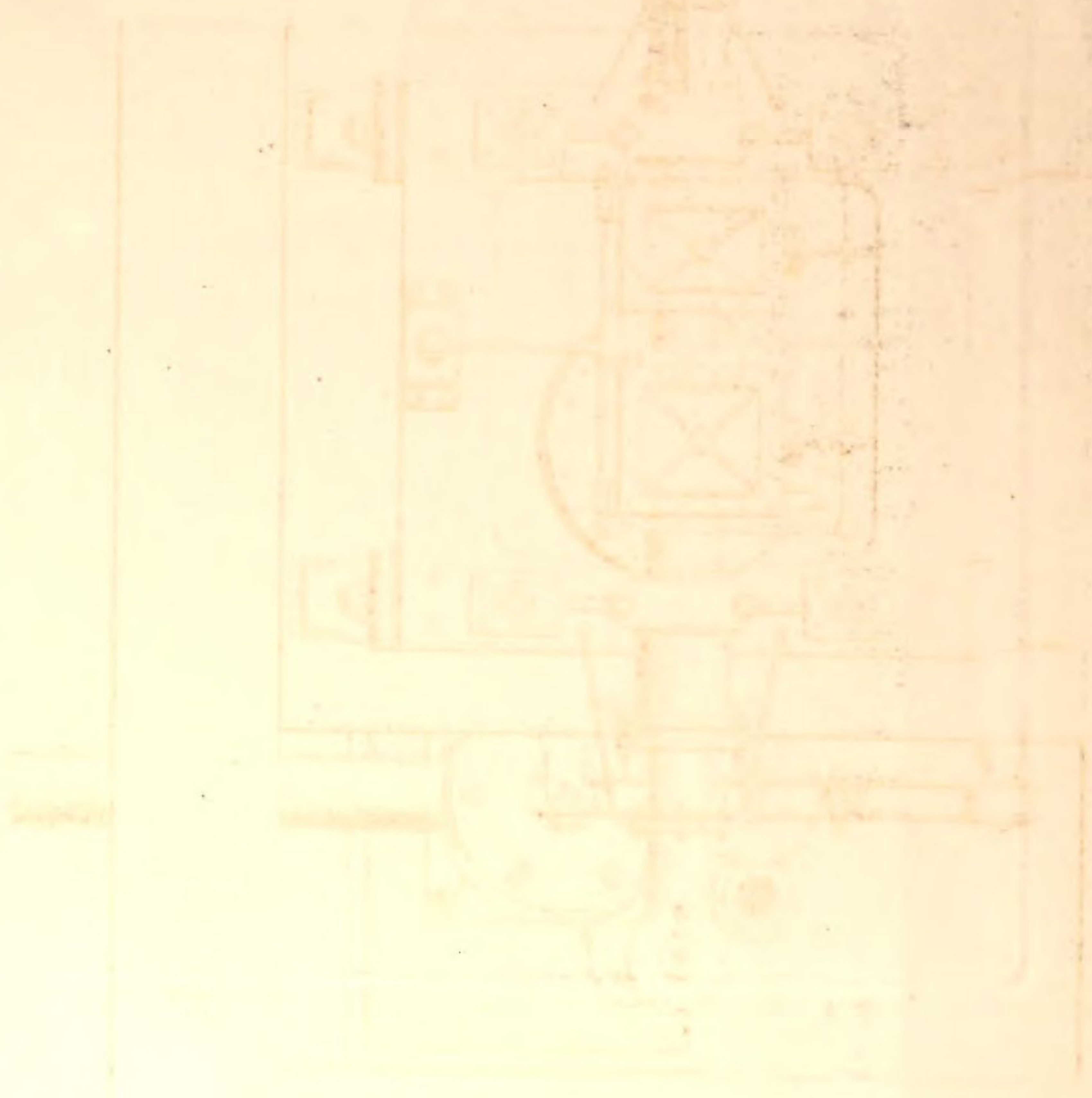
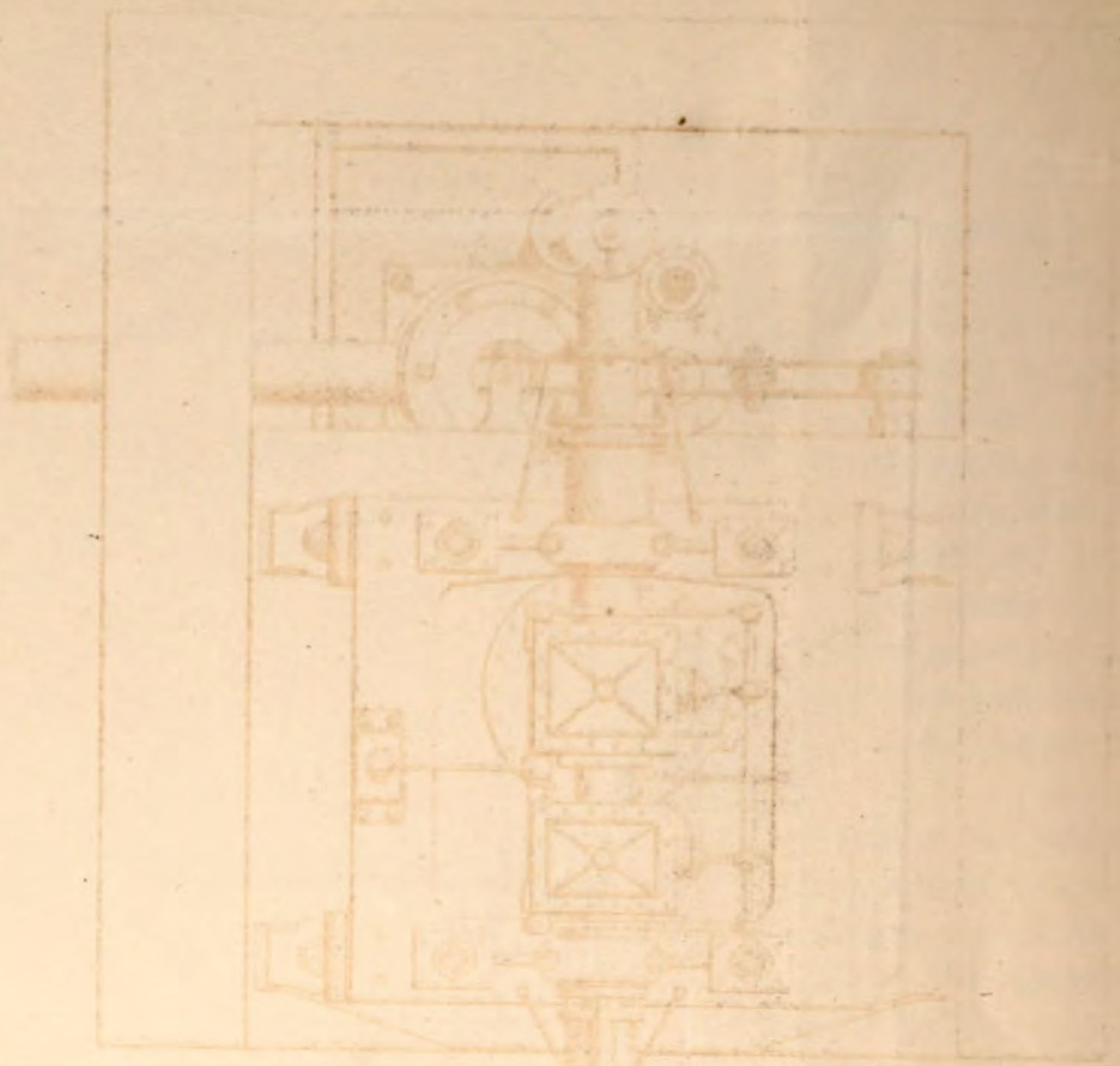
a wooden roller and enclosed in a trough of thin deal boards, suitable to its diameter: it revolves on its own axis by means of a rigger and band, at the necessary velocity to supply the elevators; and as the creeper is confined to turning in its own bearings, as a natural consequence it brings forward the grain or meal that is discharged into the trough from one end to the other.

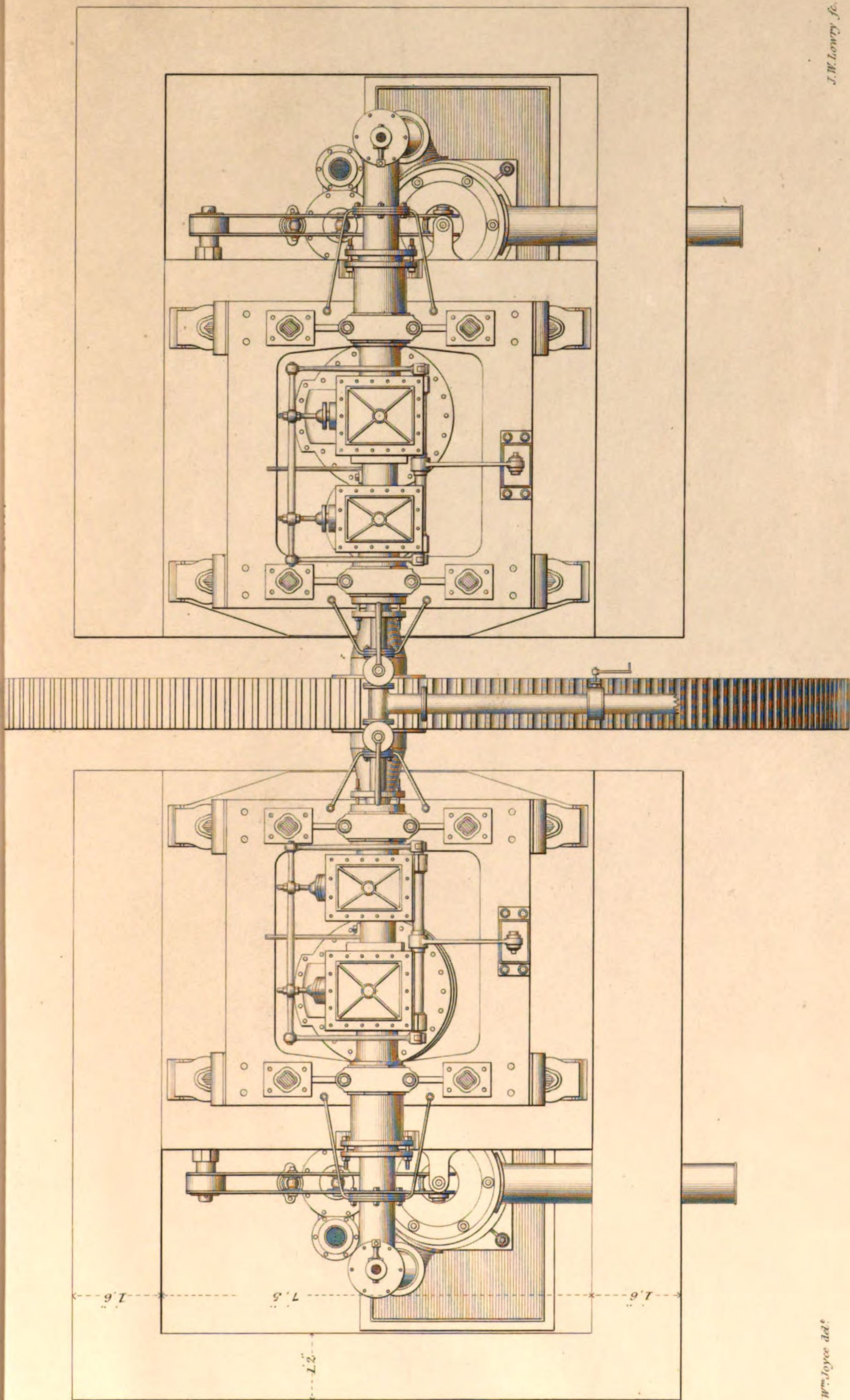
The hoist or sack tackle is a very simple affair, and is easily understood; it consists of a barrel on a spindle, revolving in bearings suspended from the roof, and the barrel is provided with rope of sufficient length to reach the lower floor of the mill: the motion is communicated to it by a band connecting a pulley on one end of the barrel with a pulley on the horizontal machine shaft of the engine: the length of this band is so arranged that the sack tackle will be kept in motion, or will remain at rest, according as the tightening rigger is pressed against this belt or not.

The gearing by which all the machinery in the upper part of the mill is worked consists of an upright shaft set in motion by bevel gear from the main horizontal shaft of the mill: this upright shaft has its foot-step supported in a cast-iron standard, similar to a mill frame, and at each floor it is supported by plumber-blocks, which are bolted to the main beams of the building: at its upper end the motion is transferred by means of another pair of bevel-wheels to a horizontal shaft passing transversely across this mill: on the shaft are fixed all the riggers for driving the dressing machines, smutter or screening machine, creepers, elevators, sack tackles, &c., &c., &c.

STEAM CORN-MILL.



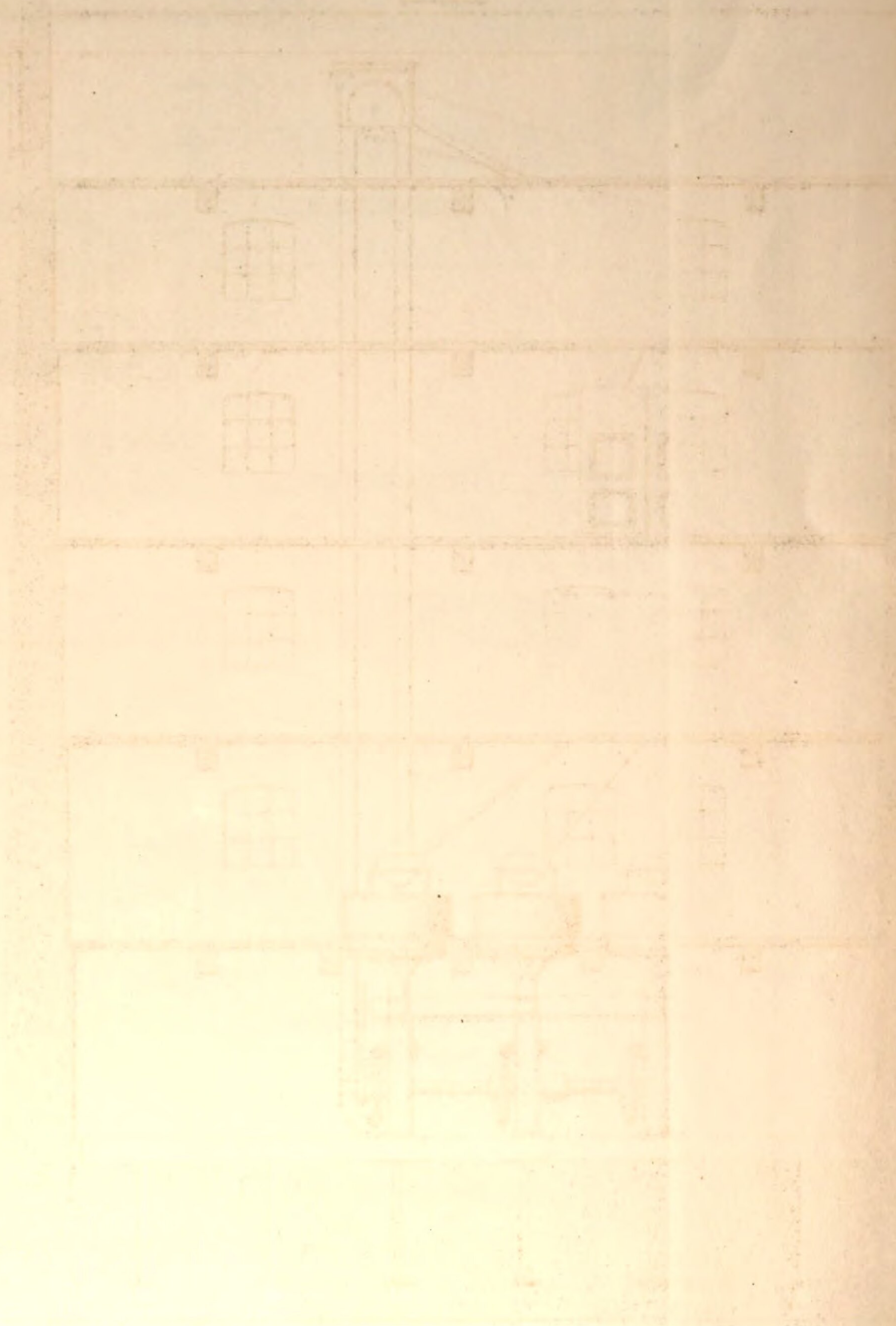
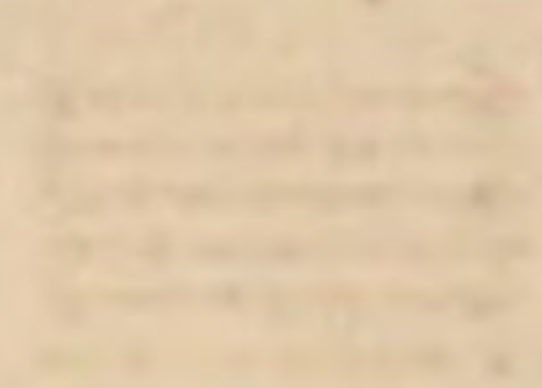


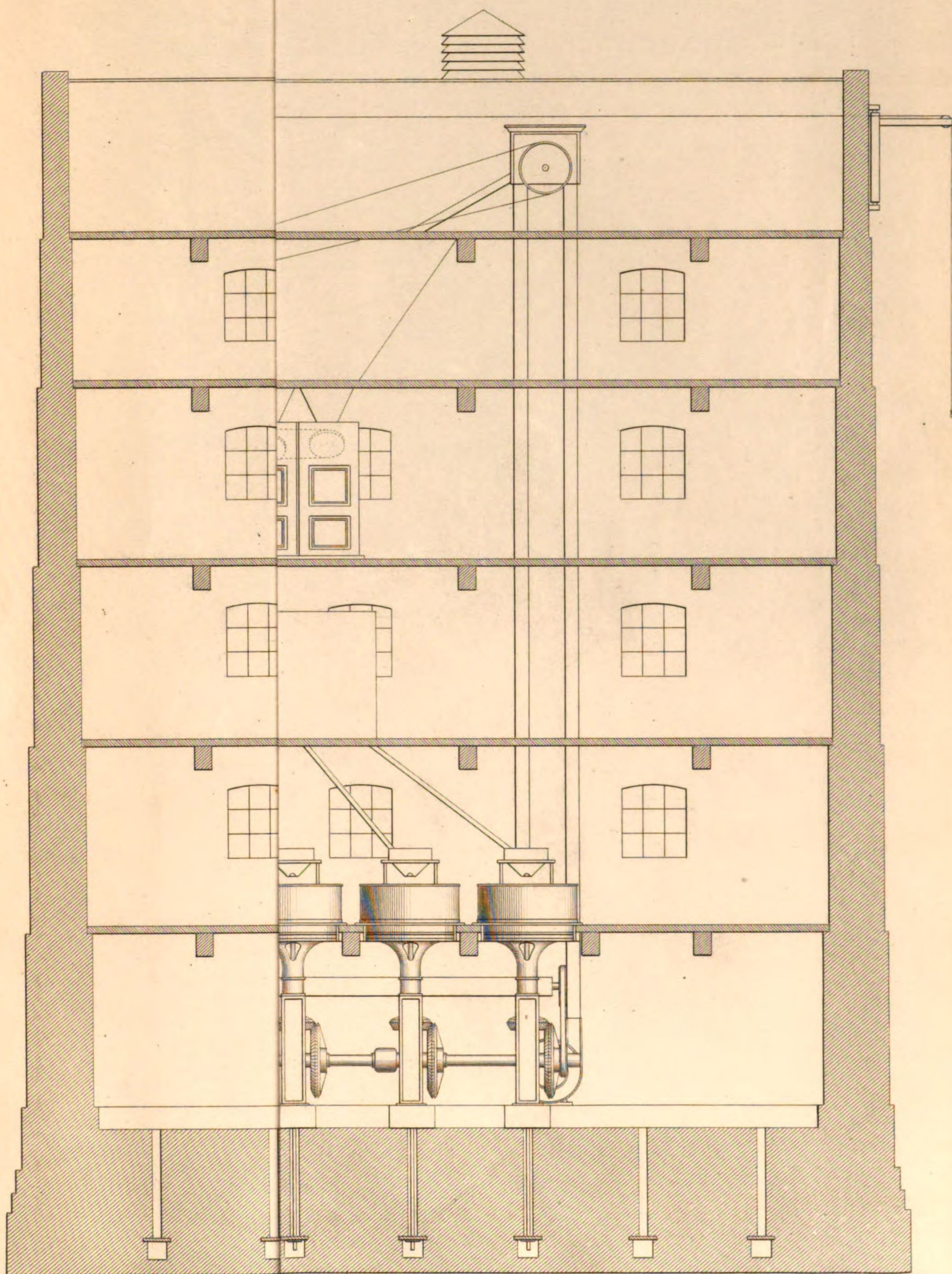


Wm. Joyce del.

London, Published by John Weale, 59, High Holborn, June 1, 1852.

J.W. Lowry fec.

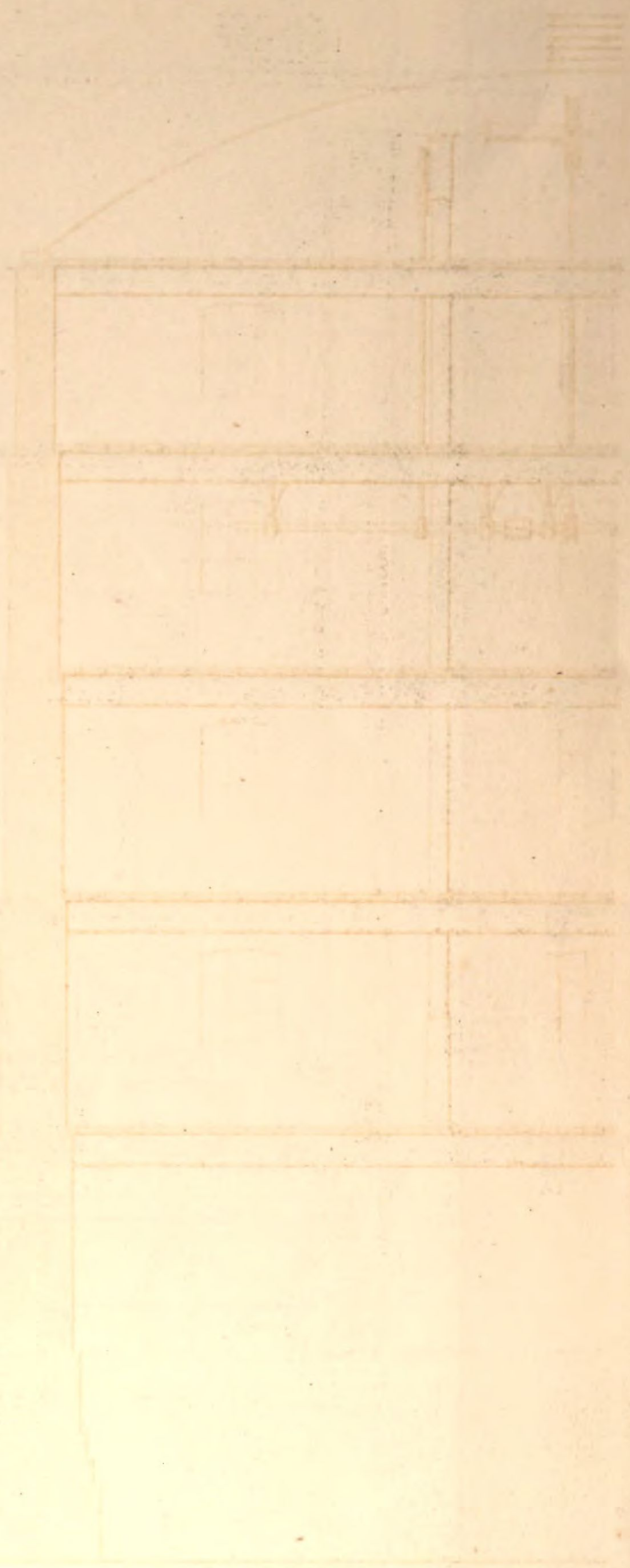


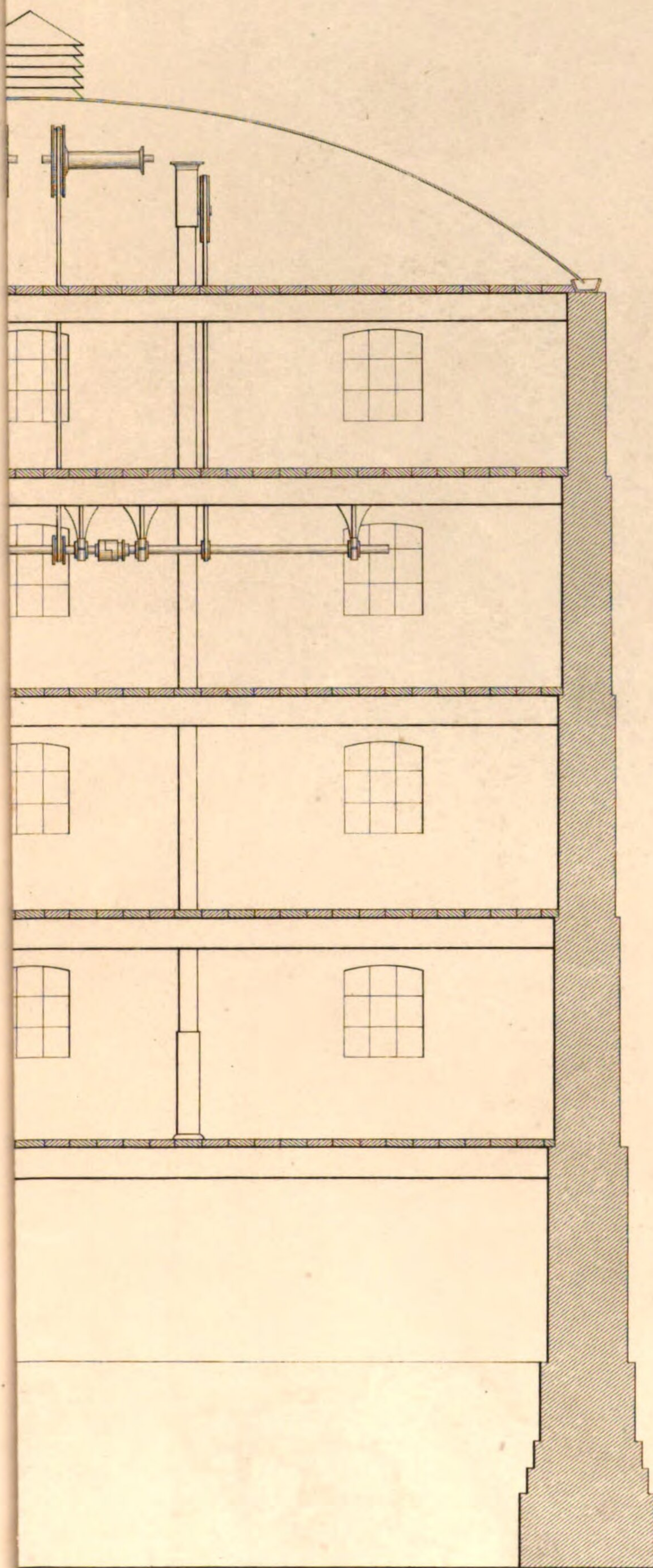


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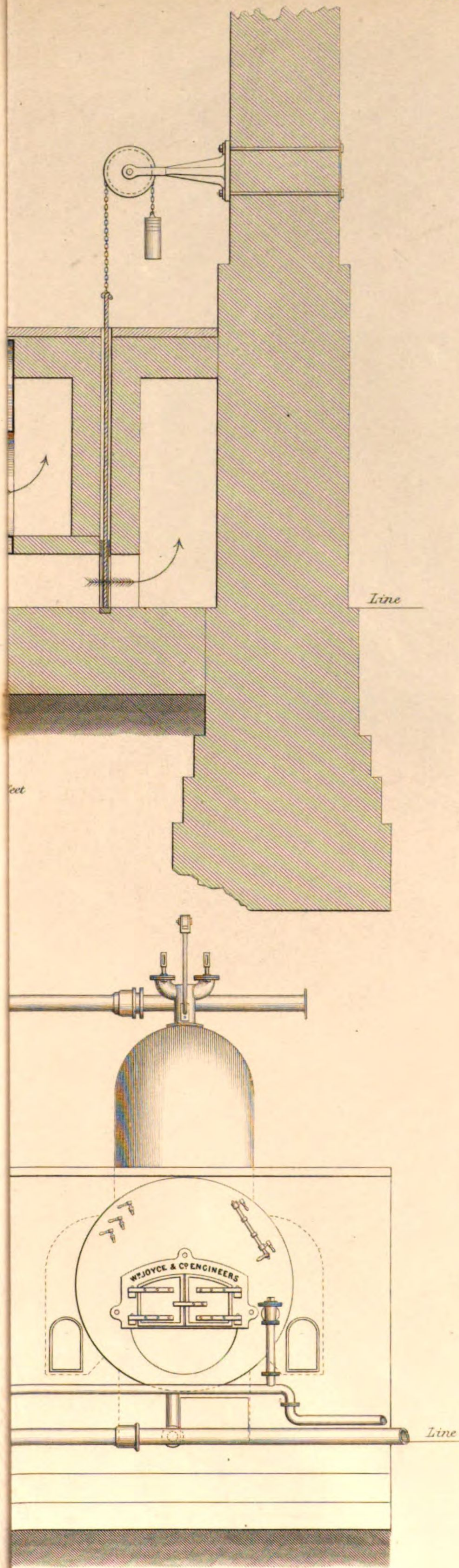




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POPULATION OF VESSELS

THE SCREW

Y. R. BODMER, U.S.

ON THE SCREW-PROPELLER.

In investigating the effect produced by a screw-propeller upon the ship with which it is connected, it appears evident that the blades of the propeller act upon the water as planes, and that the total resistance produced by their action must be equal to the resistance which the ship has to overcome in passing through the water at the required velocity. It is also evident that this resistance must be equal to the effect produced by the engine, after deducting the requisite allowances for the friction of the machinery.

THE PROPULSION OF VESSELS

The blade of the propeller, being a portion of the thread of a screw, may be considered to be composed of a series of inclined planes, each having a different angle of inclination, as that of the outer edge of the blade, and the average angle of inclination.

THE SCREW.

Let r be the radius of the screw, ω the angular velocity of the screw, v the linear velocity of the point upon which the blade is said to be concentrated, and ωv the velocity of the same time represents the rotatory velocity of the blades, it will be possible to ascertain the moment of resistance of the propeller. This point of concentrated resistance, or of pressure, evidently lies in a line dividing the area of the thread of the screw into two equal portions; and if we call γ the radius of gyration, P the mechanical pitch of the screw, and α the average angle of inclination, we shall have

BY R. BODMER, C. E.

Robert Kane, Esq., in his work on the Screw-Propeller, has furnished Tables from which the radius of gyration and the area of the blade may be ascertained. These data may, however, with sufficient accuracy, be obtained for any given screw, by dividing the height of the blade—that is, the distance between the points of the screw and that of its base or centre—into any convenient number of equal parts, and letting the distance from each point of division to the centre be, calculating the distances corresponding to each by means of the formulae

The average of these circumferences multiplied by the height of the blade, will then give the area of the thread, and that area divided by the proportion of the length of the blade to the screw will give the area of the blade. Having done this, the radius of gyration γ will then be ascertained.

It will thus be seen that the area of the blade and the radius of gyration, and consequently the moment of resistance of the screw, may be ascertained.

ON THE SCREW-PROPELLER.

IN investigating the effect produced by a screw-propeller upon the ship with which it is connected, it appears evident that the blades of the propeller act upon the water as planes, and that the total resistance produced by their action must be equal to the resistance which the ship has to overcome in passing through the water at the imparted velocity. It is also evident that this resistance must be equal to the effect produced by the engine, after having made the requisite allowances for the friction of the working parts of the engine itself, for that of the machinery connecting it with the propeller, and for the additional friction arising from its load.

The blade of the propeller, being a portion of the thread of a screw, may in fact be considered to be composed of an infinite number of minute inclined planes, each having a different angle of incidence; so that if the area of the blade, and the average angle of incidence, can be ascertained, and the vertical distance from the axis to the point upon which the whole resistance may be said to be concentrated, and whose velocity at the same time represents the rotatory velocity of the blades, it will be possible to ascertain the moment of resistance of the propeller. This point of concentrated resistance, or of gyration, evidently lies in a line dividing the area of the thread of the screw into two equal portions; and if we call y the radius of gyration, P , the mechanical pitch of the screw, and α the average angle of incidence, we shall have

$$\sin.^2 \alpha = \frac{P^2}{(2\pi y)^2 + P^2}.$$

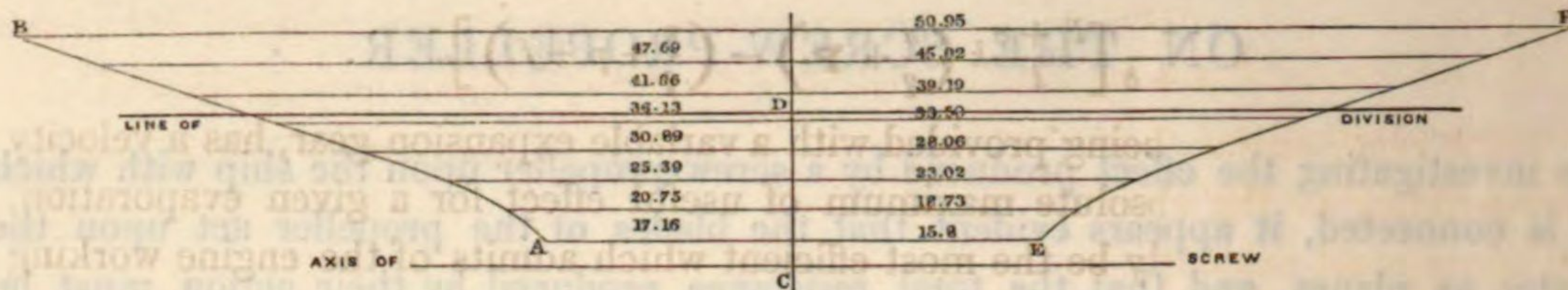
Robert Rawson, Esq., in his work on the Screw-Propeller,¹ has furnished Tables from which the radius of gyration and the area of the blade can be ascertained. These data may, however, with sufficient accuracy, be obtained for any given screw, by dividing the height of the blade—that is, the difference between the radius of the screw and that of its boss or centre—into any convenient number of equal parts, and, calling the distance from each line of division to the centre R , calculating the circumference corresponding to each by means of the formula

$$\sqrt{(2\pi R)^2 + P^2}.$$

The average of these circumferences, multiplied by the height of the blade, will then give the area of the thread, and that again reduced in the proportion of the length of the blade to the mechanical pitch produces the area of the blade. Having done this, the radius of gyration y is easily found by approximation.

¹ 'The Screw-Propeller; an investigation of its geometrical and physical properties, and its application to the propulsion of vessels,' 1851.

According to this rule, the area of the thread of the screw of the 'Arrogant' produces, in its development, the following figure, where $CD = y$; $ABE =$ area of the thread.



Supposing then that we call A the area of each blade; ϕ the number of blades in the screw; N , the number of revolutions of the screw, per minute; and Δ a coefficient which will be hereafter explained, we shall have

$$\left(\frac{N\pi y}{30}\right)^2 \phi \Delta \sin.^2 a A$$

for the moment of resistance upon a point lying at the vertical distance y from the axis of the screw. And if we further call P the effective pitch of the screw—that is, the distance the ship advances for every revolution of the screw—and K the moment of resistance of the ship divided by the square of its velocity in feet per second, we shall find

$$\frac{2\pi y}{P} \left(\frac{N\pi y}{30}\right)^2 \phi \Delta \sin.^2 a A = \left(\frac{N P}{60}\right)^2 K \dots (1.)$$

whence we deduce

$$P = 2\pi y \sqrt{\frac{\phi \Delta \sin.^2 a A}{K}} \dots (2.)$$

On the other hand, if we call γ the number of cylinders of which the engine is composed; a the area of each cylinder, in square feet; l the length of the stroke, in feet; r the load of the engine, in lbs. per square foot of each piston; and C the number of times the velocity of the screw is increased, as compared with the velocity of the engine crank-shaft, we have also

$$\frac{2\pi y}{P} \left(\frac{N\pi y}{30}\right)^2 \phi \Delta \sin.^2 a A = \frac{2\gamma a l r}{C P} \mp R,$$

which reduces itself to

$$C N^2 \pi^3 y^3 \phi \Delta \sin.^2 a A = 450 \left[2\gamma a l r \mp C P R \right] (2a).$$

Or if we apply De Pambour's formulæ and notations, as set forth in his 'Theory of the Steam Engine,'¹ we have, calling N the number of revolutions of the crank-shaft, and R , any moment of force, acting either in, or contrary to, the direction of the ship's motion, independently of the engine,

$$N^3 C^3 \pi^3 y^3 \phi \Delta \sin.^2 a A + \frac{450 N}{(1+\delta)} \left[2\gamma a l \left(\frac{n}{q} + p + f \right) \pm (1+\delta) C P R \right] = \frac{450 \gamma S k}{(1+\delta) q} \dots (3.)$$

whence, the screw being given, and the water to be evaporated per minute for the use of each cylinder, the number of revolutions N of the crank-shaft of the engine

¹ In octavo, 1839.

may be found. This formula is applicable so long as the velocity of the crank-shaft is greater than the velocity corresponding to the maximum of useful effect; after that point is attained, formula (2 a) must be applied, making

$$r = \frac{1}{1+\delta} \left[\frac{l'+c}{l} k \left(\frac{n}{q} + P \right) - \left(\frac{n}{q} + p + f \right) \right].$$

Since every engine, being provided with a variable expansion gear, has a velocity corresponding to the absolute maximum of useful effect for a given evaporation, that screw must evidently be the most efficient which admits of the engine working at such velocity. Supposing, therefore, the absolute maximum of useful effect to be represented by

$$\gamma a r_{\parallel} v_{\parallel}$$

we obtain

$$K \frac{N^3 P^3}{60^3} = \gamma a r_{\parallel} v_{\parallel};$$

whence we deduce, knowing N ,

$$P^3 = \frac{60^3 \gamma a r_{\parallel} v_{\parallel}}{N^3 K} \dots \dots (4.)$$

Having thus found P , made $P = P_{\parallel}$, assumed the number of the blades, and taken the diameter of the screw in accordance with the immersion of the ship, and with a view to keep it under water under all circumstances, it is easy to find in the first place y and $\sin.^2 a$, and subsequently, from equation (2), the area A of the blade.

It is apparent from equation (2), that with a given screw, P depends altogether upon the value of K . The mechanical pitch of the screw has, in fact, only in so far anything to do with the effective pitch as it affects the area of the thread, and the quantities y and $\sin.^2 a$; and it cannot therefore be a matter for surprise, that where K is very small as compared with $\phi \Delta \sin.^2 a A$, P should actually exceed $P_{\parallel}$. Any moment of force, moreover, acting either contrary to, or in the direction of, the ship's motion, independently of the engine, besides influencing the velocity of the propeller, augments or diminishes the value of K , and consequently decreases or increases P . So that if we call R , such a moment of force; $R_{\parallel}$, the moment of resistance of the ship at the velocity N , of the propeller, as found by means of formula (3), but with the original or ordinary values of K and P ; K , the value of K as altered under the influence of R ; and $P_{\parallel}$, the effective pitch as altered under the influence of R , we shall have

$$R_{\parallel} = \left(\frac{N P}{60} \right)^2 K; K = K \frac{R_{\parallel} + R}{R_{\parallel}} \text{ or } = K \frac{R_{\parallel}}{R_{\parallel} + R}, \text{ and } P_{\parallel} = 2\pi y \sqrt[3]{\frac{\phi \Delta \sin.^2 a A}{K}}.$$

Besides, the value of K is not only affected by every variation in the immersion of the ship, but also by the velocity of the ship. In towing ships K must, of course, be equal to the sum of the values as applying to the tug and the ship or ships in tow.

As to the coefficient Δ which appears in the foregoing formulæ, it is most likely owing to the circumstance that the blade of the screw, instead of terminating

abruptly towards the axis, as it does at the circumference and on the sides, merges into the boss, which must have a tendency to diminish the resistance produced by its rotation in the water. On an average, the coefficient Δ appears to be $= 0.686$, although it varies somewhat with the dimensions of the screw.

If nothing has hitherto been said of the friction of the surfaces and of the cutting edges of the screw blades, it is because that friction varies as the square of the velocity of the ship, and constitutes, as well as the resistance produced by the boss of the screw, part of the quantity K .

The observations hitherto made have had reference to screws of a uniform pitch only: it is however evident, that for the purpose of ascertaining the radius of gyration and the area of the blade of a screw of an increasing pitch, the same rules may be applied, it being remembered that to each radius R corresponds a different value of P . It will be seen that the tendency of the increasing pitch is, *cæteris paribus*, to increase y , $\sin.^2 \alpha$ and A ; it may therefore be employed in cases where it is not considered desirable to increase the number of the blades or their length.

Be it also stated in this place, that if we call D the diameter of the screw, d that of its boss, and λ the length of the blade, we can put, as an approximation,

$$A = \frac{\lambda (D - d)}{2 P_i} (\sqrt{D^2 \pi^2 + P_i^2} + \sqrt{d^2 \pi^2 + P_i^2})$$

$$y = \frac{1}{2} \sqrt{\frac{D^2 + d^2}{2}}$$

$$\sin.^2 \alpha = \frac{2 P_i^2}{x^2 (D^2 + d^2) + 2 P_i^2}$$

whence, λ and P_i being given, we can ascertain the diameter D of the screw.

In order to show, on the one hand, that the foregoing formulæ produce correct results, and on the other, to indicate the manner in which they are to be used, it is intended, in the first place, to apply them to the cases of the 'Arrogant' and 'Plumper' in some of the screws connected with which the effective pitch has been found to exceed the mechanical pitch; then to the calculation of the dimensions of a screw corresponding to the absolute maximum of useful effect of the engine; and lastly, to the calculation of the effect of a moment of force acting upon the ship independent of the engine. A number of other examples follow in the Table at p. 16. As the 'Rattler' is the only ship in which the power absorbed by the friction of the working parts of the engine and propeller has been experimentally ascertained, it becomes necessary to state in this place, that in all the other cases these data are merely assumed: it is therefore very possible that these assumptions may, occasionally, be far from the truth, especially where, between one trial and another, a considerable space of time has elapsed.

The data upon which the following examples are based have been chiefly (with regard to the screw steamers of Her Majesty's Navy exclusively) taken from the Government Tables, published in this work; and, as has been already said, De

Pambour's formulæ will be made use of in the various calculations. De Pambour's work is probably sufficiently well-known by this time; but perhaps it may not be quite superfluous to state that

S Represents the quantity of water usefully evaporated, in cubic feet per minute, for each cylinder.

a, The area of the cylinder, in square feet.

l, The length of the stroke, in feet.

l_p, That part of the stroke at which the steam is cut off, in feet.

c, The clearance of the cylinder, assumed at $0.05 l$.

v, The velocity of the piston, in feet per minute—called v_1 in the case of maximum, and v_2 in that of absolute maximum of useful effect.

r, The load of the engine, in lbs. per square foot—called r_1 in the case of maximum, and r_2 in that of absolute maximum of useful effect.

p, The pressure owing to the imperfect vacuum in the cylinder, in lbs. per square foot.

f, The friction of the engine unloaded, in lbs. per square foot.

δ, The augmentation of the friction f , per unit of the load r , assumed at 0.14 .

$k = \frac{l'}{l' + c} + \log. \frac{l + c}{l' + c}$ a quantity increasing with the amount of expansion.

n and **q**, Constant quantities used in ascertaining the pressure of the steam in the cylinder; and being respectively, for condensing engines, 0.00004227 and 0.000000258 .

P, The pressure of the steam in the boiler, in lbs. per square foot.

m, The relative volume of the steam.

P_p, The pressure of the steam in the cylinder, in lbs. per square foot.

Let it also be understood that

D, Expresses the diameter of the screw, in feet.

d, The diameter of the boss, in feet.

λ, The length of the screw, in feet.

V, The velocity of the ship, in knots per hour.

V, The velocity of the ship, in feet per second.

R, The moment of resistance of the ship.

Beginning then with the 'Arrogant,' and with reference to the trial made April 12, 1849, we have, first, as regards the screw,

$$D = 15.5$$

$$d = 1.583$$

$$P_1 = 15.$$

$$\lambda = 2.5$$

$$\phi = 2;$$

from which we find

$$\text{Total area of the thread} = 219.57$$

$$A = 36.595$$

$$y = 5.1276$$

$$\sin.^2 a = 0.1725$$

$$\phi \sin.^2 a A = 12.625;$$

and as regards the engine,

$$a = 16.493$$

$$\gamma = 2.$$

$$l = 3.$$

$$N_1 = 55.5$$

$$C = 1.$$

and, if we assume $f = 2$, since

$$P_1 - p = 1872$$

$$r = 1389.46, \text{ and}$$

$$R = 18146.25;$$

whence, as

$$\mathbf{V} = 8.295, \text{ and } V = 14.015,$$

$$K = 92.38.$$

We find therefore, according to equation (2), and assuming $\Delta = 0.686$,

$$P = 14.6397, \text{ instead of } P = 15.1518,$$

so that in this particular case $\Delta = 0.7609$.

The Table contains the details of four trials with the 'Plumper,' out of which three have been selected; in the first the so-called slip of the screw was positive, whilst in the two last it was negative.

At the trial made September 1, 1848, the dimensions of the screw were,

$$D = 9.$$

$$d = 0.833$$

$$P_1 = 7.$$

$$\lambda = 1.166$$

$$\phi = 2;$$

whence we find

$$\text{Total area of the thread} = 71.42$$

$$A = 11.903$$

$$y = 3.0907$$

$$\text{Sin.}^2 \alpha = 0.1163$$

$$\phi \text{ sin.}^2 \alpha A = 2.7687;$$

and we have for the engine

$$a = 3.976$$

$$l = 2$$

$$\gamma = 2$$

$$N_1 = 99.15$$

$$C = 2.5;$$

and, assuming again $f = 2$, since

$$\mathbf{P}_1 - p = 3191.04$$

$$r = 2546.5, \text{ and}$$

$$R = 4984.5;$$

whence, as

$$\mathbf{V} = 6.369, \text{ and } V = 10.762,$$

$$K = 43.03.$$

We have therefore, according to equation (2), and assuming $\Delta = 0.686$,
 $P = 6.8628$, instead of $P = 6.512$.

At the trial made December 1, 1848, the dimensions of the screw were,

$$D = 9.$$

$$d = 0.833$$

$$P_1 = 5.583$$

$$\lambda = 1.$$

$$\phi = 2.$$

from which we find

$$\text{Total area of the thread} = 69.019$$

$$A = 12.362$$

$$y = 3.1008$$

$$\sin.^2 a = 0.07447$$

$$\phi \sin.^2 a A = 1.8411;$$

and since

$$P_1 - p = 3340.8$$

$$r = 2678.4, \text{ and}$$

$$R = 5212;$$

whence, as

$$V = 7.418, \text{ and } V = 12.533,$$

$$K = 33.19.$$

We have therefore, according to equation (2), assuming $\Delta = 0.686$,

$$P = 6.552, \text{ instead of } P = 6.539.$$

Finally, at the trial made April 9, 1849, the dimensions of the screw were,

$$D = 8.77$$

$$d = 0.833$$

$$P_1 = 4.542$$

$$\lambda = 0.833$$

$$\phi = 2;$$

from which we obtain

$$\text{Total area of the thread} = 63.435$$

$$A = 11.639$$

$$y = 3.0526$$

$$\sin.^2 a = 0.05308$$

$$\phi \sin.^2 a A = 1.2356;$$

and since

$$P_1 - p = 2651.04$$

$$r = 2073.6, \text{ and}$$

$$R = 4906;$$

whence, as

$$V = 7.228, \text{ and } V = 12.212,$$

$$K = 32.92.$$

We find therefore, according to equation (2), assuming $\Delta = 0.686$,

$$P = 5.662, \text{ instead of } P = 5.378.$$

For the purpose of ascertaining, next, what would have to be the dimensions of a screw corresponding to the velocity of absolute maximum of useful effect of the

engine of the 'Arrogant,' it is requisite, in the first place, to ascertain the evaporation of the engine. According to the data of the Table, and assuming the steam to have been cut off at 0.75 of the stroke, we find

$$S = a v \frac{n + q \left((1 + \delta) r + p + f \right)}{k} = 2.911;$$

and since it is stated that the pressure of the steam in the boiler was 5 lbs. above the atmospheric pressure, we also have

$$P = 2838.24.$$

Further, in the case of absolute maximum of useful effect, we have

$$\frac{l'}{l} = \frac{\frac{n}{q} + p + f}{\frac{n}{q} + P};$$

therefore in this case

$$\frac{l'}{l} = 0.327,$$

that is, the steam would have to be cut off at 0.327 of the stroke, which gives

$$k = 1.892.$$

And as

$$a r_{II} v_{II} = \frac{S}{(1 + \delta) q} \left[k - \frac{l}{l' + c} \cdot \frac{n + q(p + f)}{n + qP} \right]$$

we find

$$\gamma a r_{II} v_{II} = 20289676.$$

Also, because

$$v_{II} = \frac{m S}{a} \cdot \frac{l}{l' + c},$$

we have

$$v_{II} = 607.54$$

$$N_I = 101.25.$$

We find therefore, from equation (4),

$$P = 9.1328;$$

and if we make $P = P_I$, reducing at the same time the diameter of the screw, and increasing the number of the blades, so as to call

$$P_I = 9.133$$

$$D = 8$$

$$\phi = 6,$$

we obtain, by the means previously indicated,

$$\text{Total area of the thread} = 57.53$$

$$y = 2.7578$$

$$\sin.^2 \alpha = 0.2159;$$

and, taking $\Delta = 0.7609,$

$$A = 13.72$$

$$\lambda = 2.177;$$

which gives us

$$V = 9.123; R = 21954.$$

In the case of the maximum of useful effect, assuming the steam to be cut off at 0.75 of the stroke, we should, by a similar process to the foregoing, obtain

$$N_1 = 47.72$$

$$P = 18.142,$$

and, retaining the same diameter and mechanical pitch and number of blades of the screw,

$$A = 62.842$$

$$\lambda = 4.293,$$

whence

$$V = 8.539$$

$$V = 14.428, \text{ and}$$

$$R = 19231.$$

With four blades we should have

$$\lambda = 2.1465, \text{ and } A = 31.42.$$

If we now suppose the 'Arrogant' with a screw of the dimensions specified in the Table, and retaining $S = 2.911$ and $\frac{l''}{l} = 0.75$, to be under the influence of a moment of force $R_1 = 8000$ lbs. acting in a direction contrary to the motion of the ship, we shall find, by means of formula (3),

$$N_1 = 48.95.$$

This gives us

$$R_{11} = \left(\frac{N_1 P}{60}\right)^2 K = 14115,$$

whence we derive

$$K_1 = \frac{R_{11} + R_1}{R_{11}} K = 144.667;$$

and since

$$P_{11} = 2\pi y \sqrt[3]{\frac{\phi \Delta \sin^2 \alpha A}{K_1}}$$

we shall have

$$P_{11} = 13.0449,$$

whence

$$V = 6.3$$

$$V = 10.642.$$

On the other hand, if the moment of force R_1 , instead of acting contrary to, acted in favour of the vessel's motion, we should find, by a similar proceeding,

$$N_1 = 62.35$$

$$R_{11} = 22901$$

$$K_1 = 68.45$$

$$P_{11} = 16.7402$$

$$V = 10.29$$

$$V = 17.396.$$

In conclusion, let it be observed, that although the quantity K is one of the most essential elements in the calculation of the screw-propeller,—in the case of a ship which is yet to be constructed, its value can only be arrived at by comparison with

other ships having been built upon the same or similar lines : and, if we call M the greatest immersed transverse section of the ship, ρ a coefficient which becomes larger or smaller as the ship is of an inferior or better construction, and β another coefficient increasing with the velocity of the ship, we may put $K = \rho \beta M$. Having, after considering all the circumstances, assumed a value for K , and fixed upon the dimensions and other particulars of the engine,—the evaporation S being also known,—it only remains to ascertain the dimensions of the propeller, as corresponding to the absolute maximum of useful effect of the engine, in the manner indicated. It must be stated, however, that instead of constructing the screw so as to correspond strictly to the absolute maximum of useful effect of the engine, it would probably be better to modify its dimensions upon the supposition of an average external resistance.

Should it not be considered desirable to go beyond a certain amount of expansion, a screw answering to the maximum of useful effect for the limit fixed may be employed with advantage.

As practical men generally have an objection to mathematical formulæ, it may not be superfluous to enter into the elucidation of the subject in more general terms. The blades of the screw must be considered as so many inclined planes impinging upon the water at a certain velocity, which is equal to the velocity of the circumference corresponding to the radius of gyration ; and the square of the sine of the angle of incidence multiplied by the area of the blades, and by the square of that velocity, must give the moment of resistance as to a point lying at the vertical distance of the radius of gyration from the axis of the screw. Now this resistance, increased in the proportion of the circumference of gyration to the effective pitch of the screw, must evidently be equal to the moment of resistance of the ship.

Let it be supposed, therefore, that a ship is being constructed, whose greatest immersed transverse section is 580 square feet ; that this ship is intended to be fitted with an engine of two cylinders, each of 55 inches diameter, and having a stroke of 3 feet ; that the engine is to act upon the screw without intermediate gearing ; that the steam is to be cut off after the piston has performed three parts of its stroke ; that the pressure of the steam in the boilers is to be 5 lbs. per square inch beyond the atmospheric pressure ; and that the evaporation amounts to 2.911 cubic feet per minute for each cylinder. What are the dimensions of the most efficient screw for such a ship ?

To solve this problem, we must, in the first place, ascertain the number of revolutions of the propeller, and the effect of the engine in lbs. raised 1 foot high per minute. As the volume of the steam corresponding to a pressure of $5 + 14.71 = 19.71$ lbs. per square inch is 1298 ; and as the steam is cut off at three-fourths of the stroke, if we allow $\frac{1}{20}$ th for the clearance of the cylinder, the velocity of the

piston will be 286.32 feet, and that of the propeller 47.72 revolutions per minute. For as the area of the cylinder is 16.49 square feet, we have

$$\frac{2.911 \times 1298}{16.49} \times 1.25 = 286.32 \text{ feet, and}$$

$$\frac{286.32}{2 \times 3} = 47.72 \text{ revolutions.}$$

And since the average pressure in the cylinder with the given expansion is 2838.24 lbs. per square foot, if we deduct 288 lbs. per square foot for the friction of the working parts of the engine and propeller, and 531 lbs. per square foot for the imperfect vacuum in the cylinder, and divide the remainder by 1.14 for the additional friction arising from the load, we shall have for the net effect of the engine

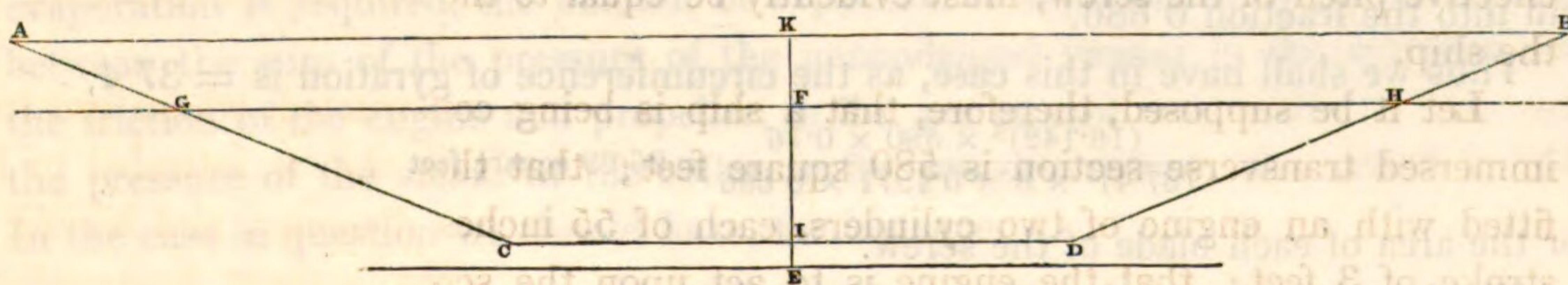
$$2 \times 16.49 \times 286.32 \times 1763.4 = 16652242 \text{ lbs.}$$

raised 1 foot high per minute.

If we multiply the above by 3600, and divide by the product of the number of revolutions of the propeller, raised to the third power, into the area of the greatest transverse section of the ship, and into the fraction 0.16; the 3rd root of the quotient will be the effective, and may be taken as the mechanical pitch of the screw. In this case then we have

$$\sqrt[3]{\frac{3600 \times 16652242}{(47.72)^3 \times 580 \times 0.16}} = 18.142 \text{ feet.}$$

Supposing now that we assume the diameter of the screw at 15 feet 6 inches, and the number of the blades at 3, we may, by approximation, ascertain the length and area of the blade and the other requisites in the following manner:



Draw a straight line, make it equal in length to the circumference of the screw; at the end of it raise a perpendicular and make it equal in length to the pitch, and draw the hypotenuse, which call A B. Also draw another straight line, make it equal in length to the circumference of the boss of the screw; at the end of it raise a perpendicular, make it equal in length to the pitch, and draw the hypotenuse, which call c d. Place A D and c d parallel to each other at a distance equal to the difference between the radii of the screw and its boss, and join the points A and c, B and d respectively; then draw another line at the distance of the radius of the boss from, and parallel with, c d. (See above.)

Then, to find the radius of gyration, add together the squares of the diameters of

the screw and its boss, divide by 2 and extract the square root, and divide by 2 once more. Thus we shall have in this case

$$\frac{1}{2} \sqrt{\frac{240 \cdot 25 + 2 \cdot 51}{2}} = 5 \cdot 5 \text{ feet}$$

for the radius of gyration.

Make the distance from E to F equal to the radius of gyration, draw a line through the point F parallel to the line AB until it intersects the lines AC and BC at G and H; measure the line GH, divide the pitch by it, and square the quotient, and the result will be the square of the sine of the angle of incidence.

Thus we shall have in this case, as $GH = 40 \cdot 833$,

$$\left(\frac{18 \cdot 142}{40 \cdot 838} \right)^2 = 0 \cdot 1971$$

for the square of the sine of the angle of incidence.

Next, in order to ascertain the area of the thread of the screw, add together the lengths AB and CD, divide by 2, and multiply by the difference IK of the radii of the screw and its boss.

Thus we shall have in this case, as

$$AB = 51 \cdot 91, CD = 18 \cdot 83, \text{ and } IK = 6 \cdot 96,$$

$$\frac{51 \cdot 91 + 18 \cdot 83}{2} \times 6 \cdot 96 = 246 \cdot 17 \text{ square feet}$$

for the area of the thread.

Now, to ascertain the area of each blade of the screw, divide the product of the cube of the pitch, multiplied into the greatest transverse section of the ship and into the fraction 0.16, by the product of the cube of the circumference of gyration into the number of the blades, into the square of the sine of the angle of incidence, and into the fraction 0.686.

Thus we shall have in this case, as the circumference of gyration is $= 37 \cdot 4$,

$$\frac{(18 \cdot 142)^3 \times 580 \times 0 \cdot 16}{(37 \cdot 4)^3 \times 3 \times 0 \cdot 1971 \times 0 \cdot 686} = 26 \cdot 69 \text{ square feet}$$

for the area of each blade of the screw.

The length of the blade will therefore have to be

$$\frac{26 \cdot 69}{246 \cdot 17} \times 18 \cdot 142 = 1 \cdot 967 \text{ feet.}$$

In recapitulation, the dimensions of the most effective screw under the given circumstances would have to be

$$\text{Diameter} = 15 \cdot 5 \text{ feet}$$

$$\text{Pitch} = 18 \cdot 142 \text{ feet}$$

$$\text{Area of each blade} = 26 \cdot 69 \text{ square feet}$$

$$\text{Length of each blade} = 1 \cdot 967 \text{ feet.}$$

Should it be desired to ascertain the power exerted by the engine in overcoming the resistance of a given screw at a certain velocity, it is only necessary to find the

dimensions of the screw by the means indicated, and then to divide the product of the number of revolutions of the propeller, raised to the third power, into one-half of the circumference of gyration also raised to the third power, into the number of blades of the propeller, into the square of the sine of the angle of incidence, into the area of the blade, and into the fraction 0.686—by the product of 450 into 33000.

Thus we should find, taking the foregoing case as an example,

$$\frac{(47.72)^3 \times (18.7)^3 \times 3 \times 0.1971 \times 26.69 \times 0.686}{450 \times 33000} = 574.6 \text{ H.P.}$$

And if we wished to know at what velocity the ship would go under the above circumstances, we should have to extract the cube root of the product of the number of blades into the square of the sine of the angle of incidence, into the area of the blade, and into the fraction 0.686, divided by the greatest transverse section of the ship multiplied by 0.16—and to multiply this root by the circumference of gyration.

Thus we should have

$$37.4 \times \sqrt[3]{\frac{3 \times 0.1971 \times 26.69 \times 0.686}{580 \times 0.16}} = 18.142 \text{ feet}$$

for the effective pitch of the screw. And multiplying this by 60 and by the number of revolutions of the propeller per minute, and dividing by 6082.66, we should obtain

$$8.53 \text{ nautical miles}$$

for the corresponding velocity of the ship per hour.

In cases where the very best screw for a given pressure of steam and a given evaporation is required, the amount of expansion is represented by the proportion between the sum of the pressure of the uncondensed vapour in the cylinder, and the friction of the engine and propeller, in lbs. per square foot, added to 164; and the pressure of the steam in the boiler, in lbs. per square foot, also added to 164. In the case in question we should have, for instance,

$$\frac{513 + 228 + 164}{2838.24 + 164} = 0.327,$$

which means that the steam is to be cut off after the piston has travelled over 0.327 of its stroke, or 0.981 foot. Having obtained this quantity, the proceeding is the same as that previously described. Where there is intermediate gearing, the increase in the velocity of the propeller over that of the crank-shaft of the engine must, of course, be taken into account.

There is evidently a limit to the length of the screw, as it cannot be desirable that it should occupy more than a certain moderate space. This limit may be fixed from the first, and the diameter of the screw and the number of the blades proportioned accordingly.

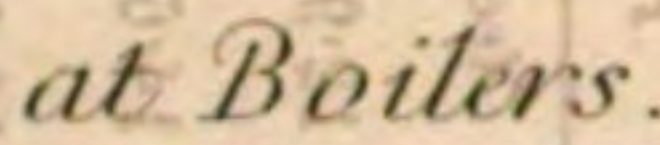
Name of ship.	Date of Experiment.	Diameter of screw.	Mechanical pitch of screw.	Length of screw.	Diameter of boss or centre.	Number of blades.	Total area of one thread.	Area of each blade.	Square of sine of angle of incidence.	Radius of gyration.	Circumference of gyration.	$\phi \Delta \sin^2 \alpha$	Area of cylinder in square feet.	No. of cylinders.	Length of stroke in feet and decimals.	Revolutions of crank-shaft per minute.	Revolutions of screw per minute.	Velocity of ship in knots per hour.	Square of velocity of ship in feet per second.	Moment of resistance of the ship.	Value of the quantity $\frac{R}{V^2}$	Effective pitch of screw, as per experiment.	Effective pitch of screw, as per formula.	Gross effect of the engine in horses' power.	Net effect of the engine in horses' power.
		D	P,	λ	d	ϕ	sq. feet	A	$\sin^2 \alpha$	y	$2\pi y$	$\phi \Delta \sin^2 \alpha$	a	γ	l	N	N'	V	V ²	R	K	P	P		
		feet.	feet.	feet.	feet.		sq. feet	sq. feet		feet.	feet.		feet.		feet.			feet.		lbs.		feet.	feet.		
Ajax . .	Dec. 12, 1848	16	20	3.666	2.25	2	246.29	45.145	0.2609	5.3532	33.635	16.160	16.494	4	2.5	42	42	6.485	119.05	+33506	281.56	15.587	12.973	878.7	667.1
Arrogant .	April 12, 1849	15.5	15	2.5	1.583	2	219.57	36.595	0.1725	5.1276	32.217	8.662	16.494	2	3	55.5	55.5	8.295	196.43	18146	92.38	15.152	14.636	623.3	462.1
Blenheim	June 5, 1849	16	20	3.333	*2.25	2	246.29	41.048	0.2609	5.3532	33.635	14.693	14.74	4	3	43	43	5.816	96.61	+39519	409.06	13.715	11.100	938.4	705.6
Dauntless	Aug. 28, 1848	14.666	18	3	*1.583	2	210.39	35.060	0.2582	4.8498	30.472	11.419	38.465	2	4	24.3	55.3	7.366	154.95	26346	170	13.507	12.387	810.9	595.8
Dwarf . .	May 5, 1843	5.666	8	1	*0.75	2	32.56	4.349	0.3172	1.8649	11.717	1.893	8.727	2	2.666	35.5	182.8	10.537	317.08	5065	15.97	5.845	5.756	216.0	163.8
Encounter	Nov. 2, 1848	12	15	2.5	1.25	2	141.43	23.572	0.2660	3.9655	24.916	8.603	16.494	2	2.25	78	78	10.254	299.95	15916	53.05	13.322	13.584	672.7	501
Fairy . .	April 5, 1845	5.333	8	1	*0.75	2	29.47	3.683	0.3326	1.3752	8.641	2.896	9.616	2	3	51.6	258	13.324	506.43	6680	13.19	5.234	5.212	363.8	273.2
Minx . .	July 1, 1848	4.5	5	1	*0.583	2	18.93	3.786	0.2167	1.5135	9.509	1.126	6.317	2	2.75	63.5	254.12	9.137	238.14	6140	25.78	3.644	3.348	234.5	172.3
Niger . .	Mar. 19, 1849	12.5	17	2.833	*1.25	2	159.52	26.586	0.3051	4.0736	25.612	11.129	12.371	4	1.833	68.8	68.8	9.494	257.12	21632	84.17	13.984	13.047	827.8	630.5
Plumper .	Sept. 1, 1848	9	7	1.166	0.833	2	71.42	11.903	0.1163	3.0907	19.419	1.899	3.976	2	2	39.66	99.15	6.369	115.82	4985	43.03	6.512	6.354	121.7	97.4
Ditto . .	Dec. 1, 1848	9	5.583	1	0.833	2	69.02	12.362	0.0745	3.1008	19.483	1.263	3.976	2	2	44.8	112	6.497	157.08	5212	33.19	6.539	6.552	149.5	104
Ditto . .	April 9, 1849	8.77	4.542	0.833	0.833	2	63.43	11.639	0.0531	3.0526	19.180	0.847	3.976	2	2	54.5	136.25	7.228	149.13	4906	32.92	5.378	5.660	139.3	108.9
Rattler .	June 27, 1844	10	11	1.25	*1	2	95.27	10.823	0.2173	3.3221	20.873	3.226	8.782	4	4	26	104	10.074	289.51	10316	35.63	9.816	9.372	428	319
Teazer .	June 8, 1847	4.5	5.833	1	*0.583	2	19.91	3.412	0.2792	1.4929	9.380	1.307	6.317	2	2.75	50	200	6.315	113.76	6582	57.73	3.200	2.654	175.6	127.6
Ditto . .	Oct. 6, 1848	5	7	1.166	*0.583	2	25.53	4.254	0.3171	1.6368	10.284	1.851	3.976	2	2.5	51.5	192.09	7.685	168.48	4101	24.34	4.054	4.351	128.2	96.7
Termagant	June 25, 1849	15.5	18	3	1.583	2	231.43	38.572	0.2365	5.1418	32.307	12.517	20.965	4	3.5	33	66	9.166	239.85	33614	140	14.081	14.444	1245.2	945.9
Ditto . .	Nov. 13, 1849	15.5	18	3	1.583	2	231.43	38.572	0.2365	5.1418	32.307	12.517	20.965	4	3.5	26	52	6.518	121.20	29312	242.24	12.703	12.031	734	586.6

* These dimensions are assumed.

† It is very probable, that when these experiments were made, the engines were in an inferior working condition.

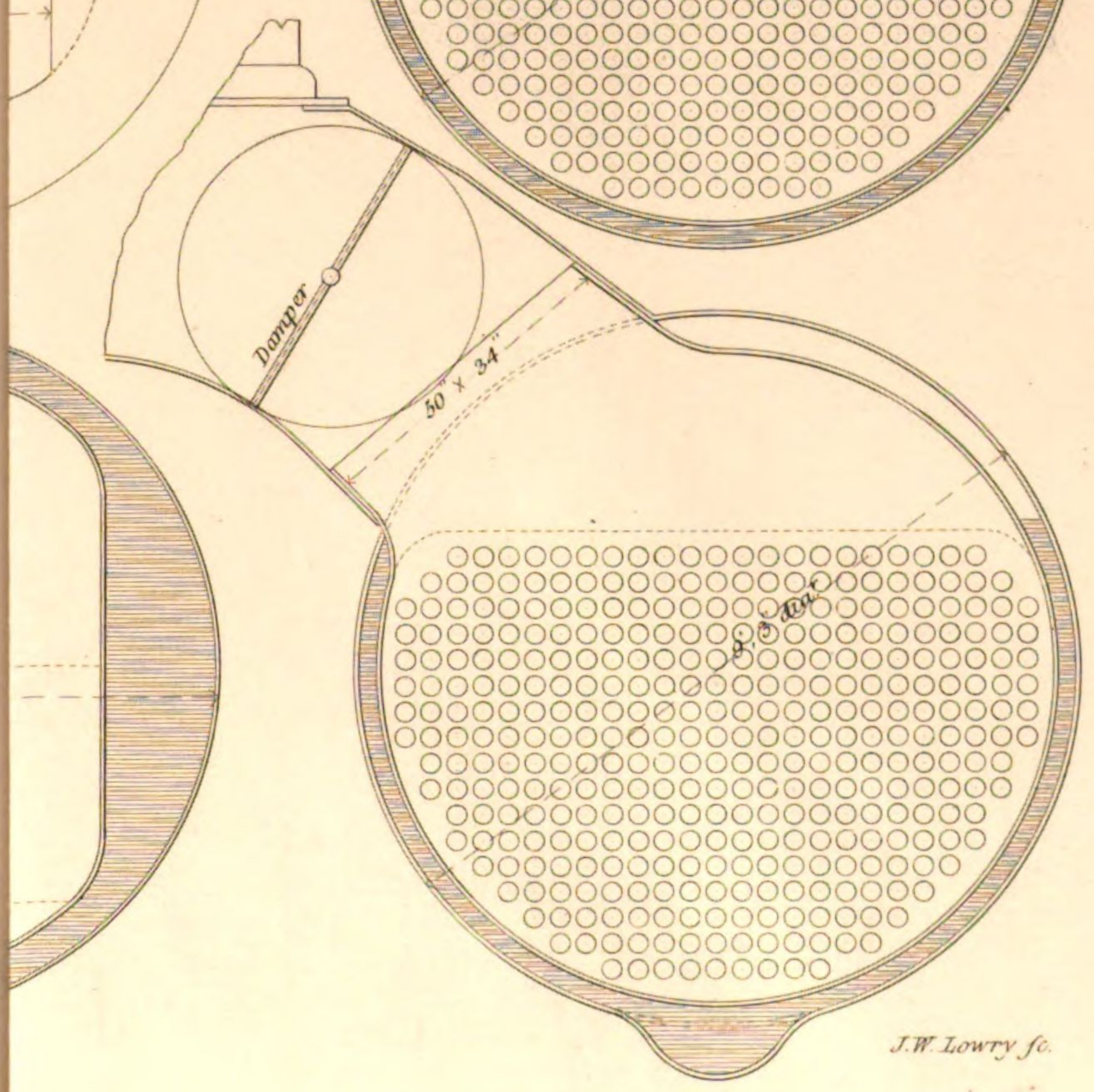
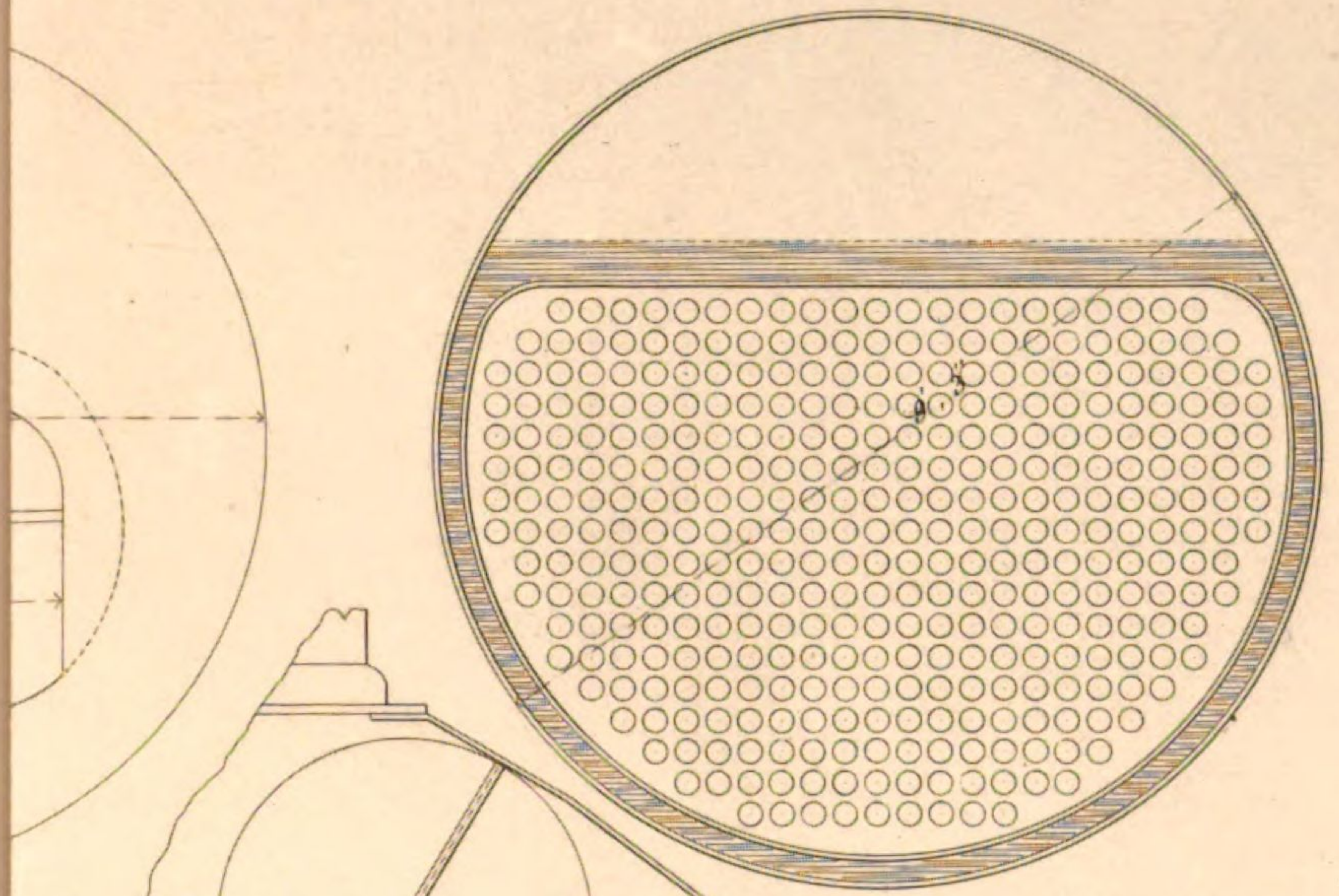
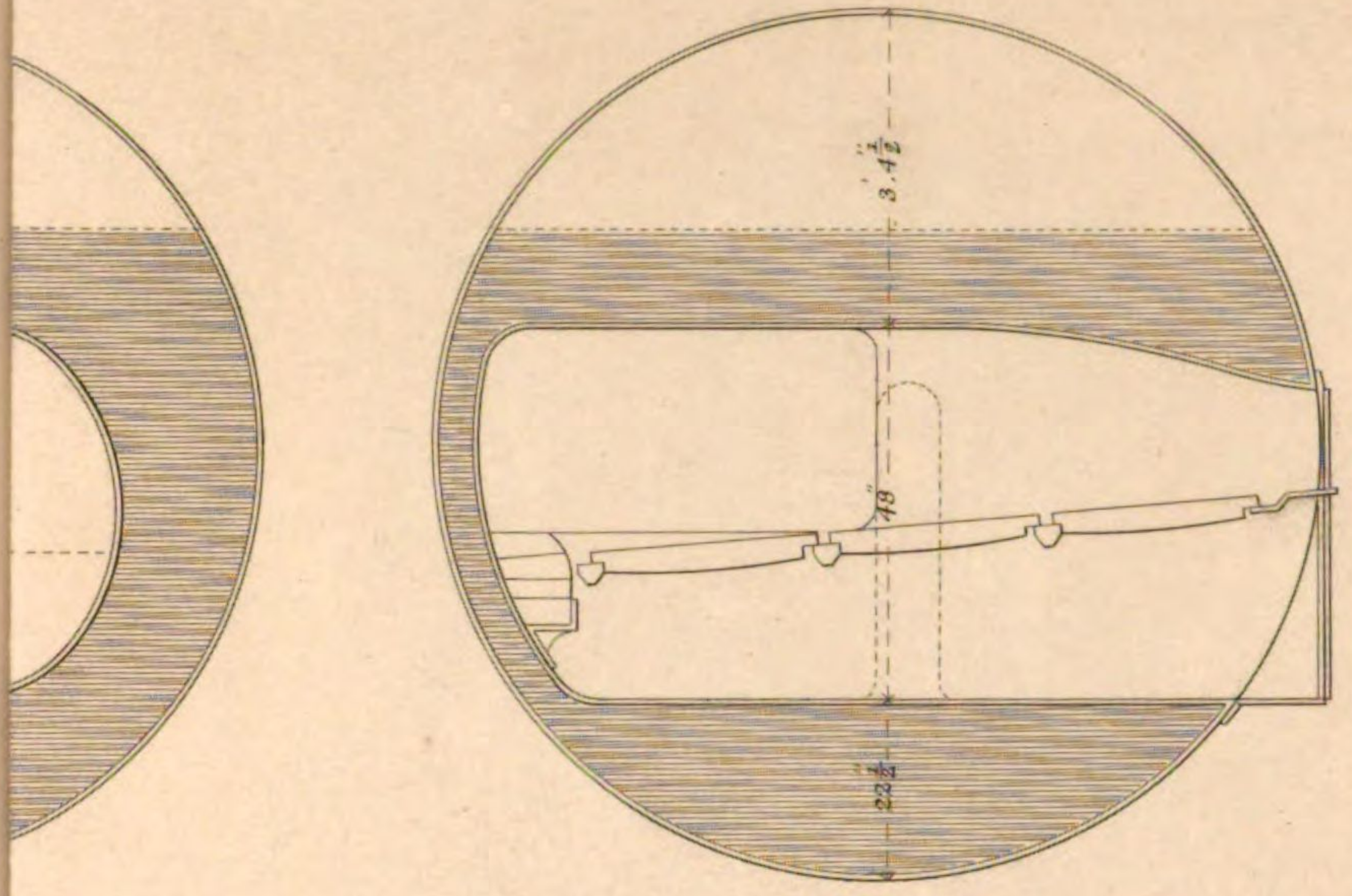
N.B. There can be no doubt that the value of the coefficient Δ varies with the angle of incidence and the number of the blades; but this point could only be ascertained by a series of carefully conducted experiments with various kinds of screws applied to the same ship. And in general it must appear evident that for every new series of experiments, the friction of the working parts of the engine and propeller ought to be carefully ascertained, as otherwise the result cannot be relied upon. In the calculation of the effective power of the engines, as given in the Table, the friction has been taken at 288 lbs. per square foot.

'REYNARD' & 'CRUISER'.

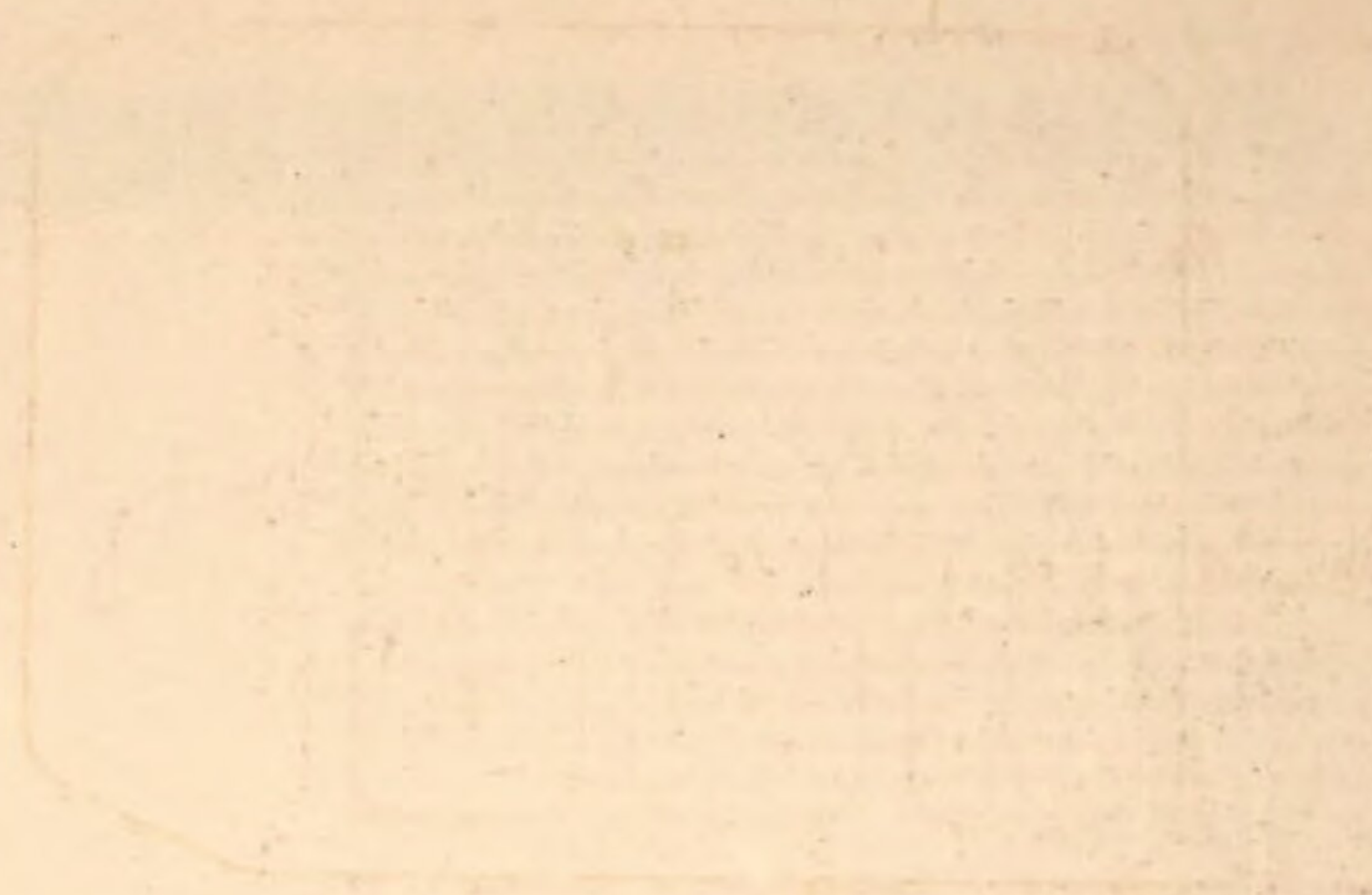


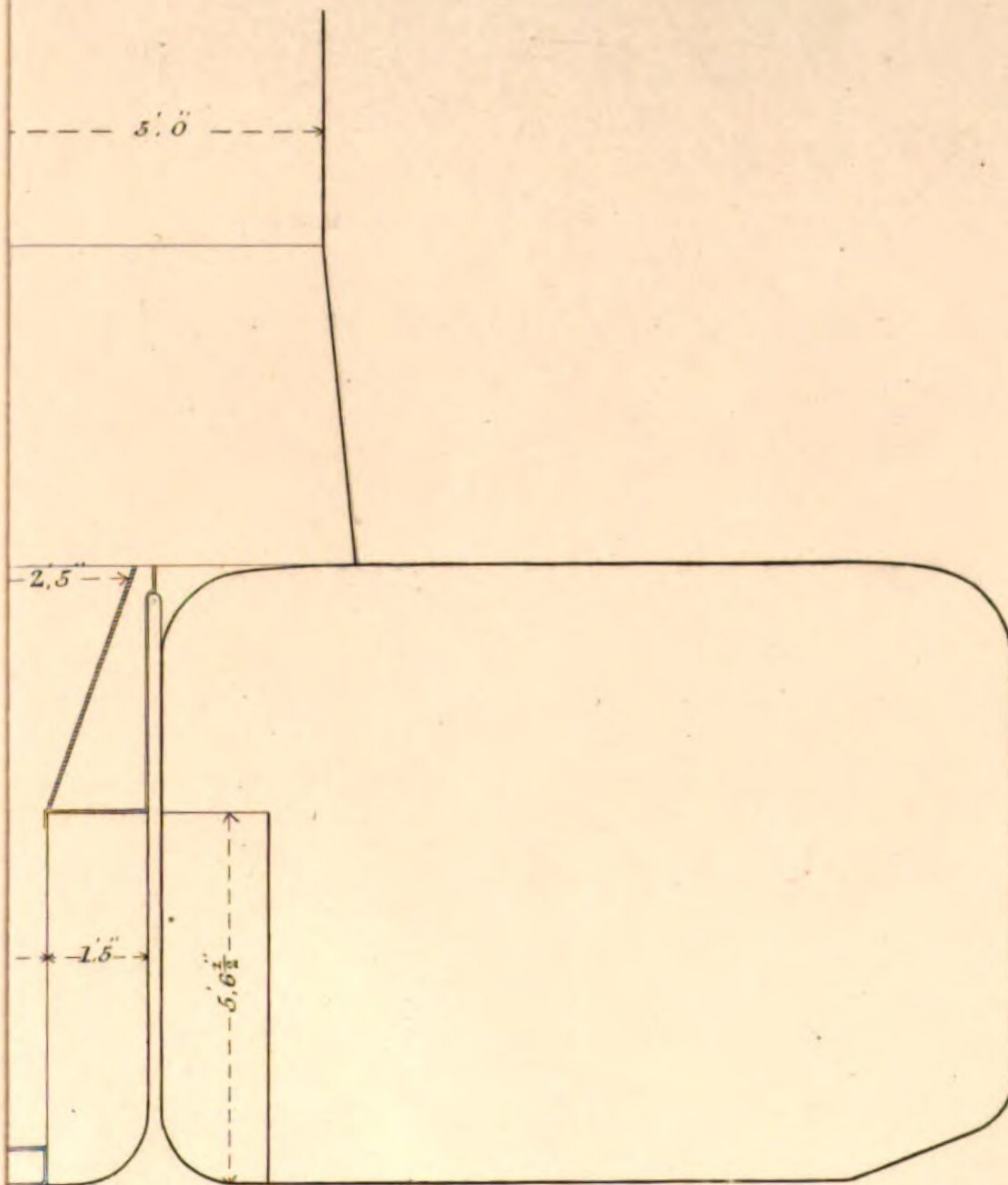
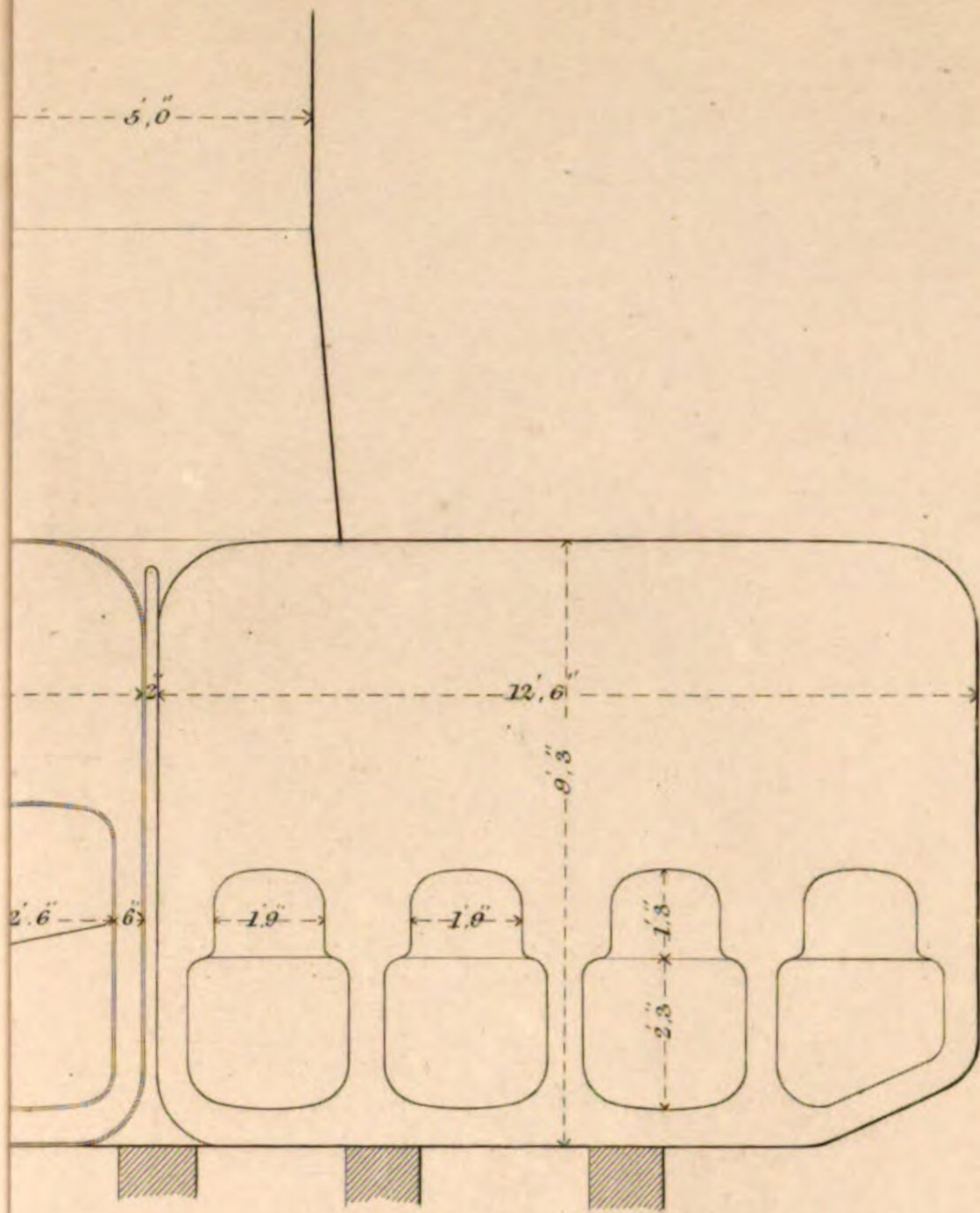
London Published by John Weale 59 High Holborn August, 1852.

15 feet



J.W. Lowry Jr.





0 7 8 9 10 11 12 Feet.

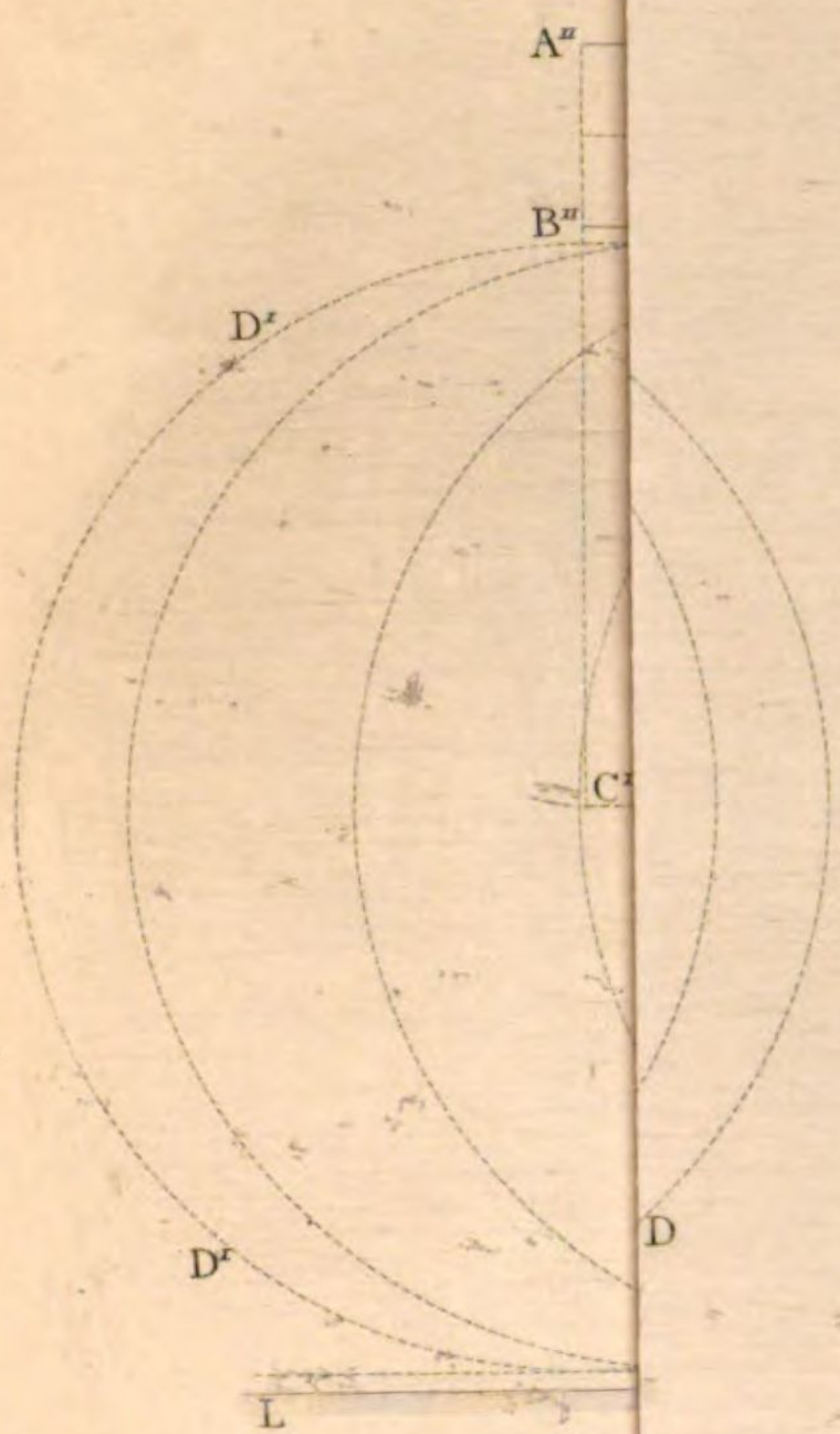


Fig. 3.

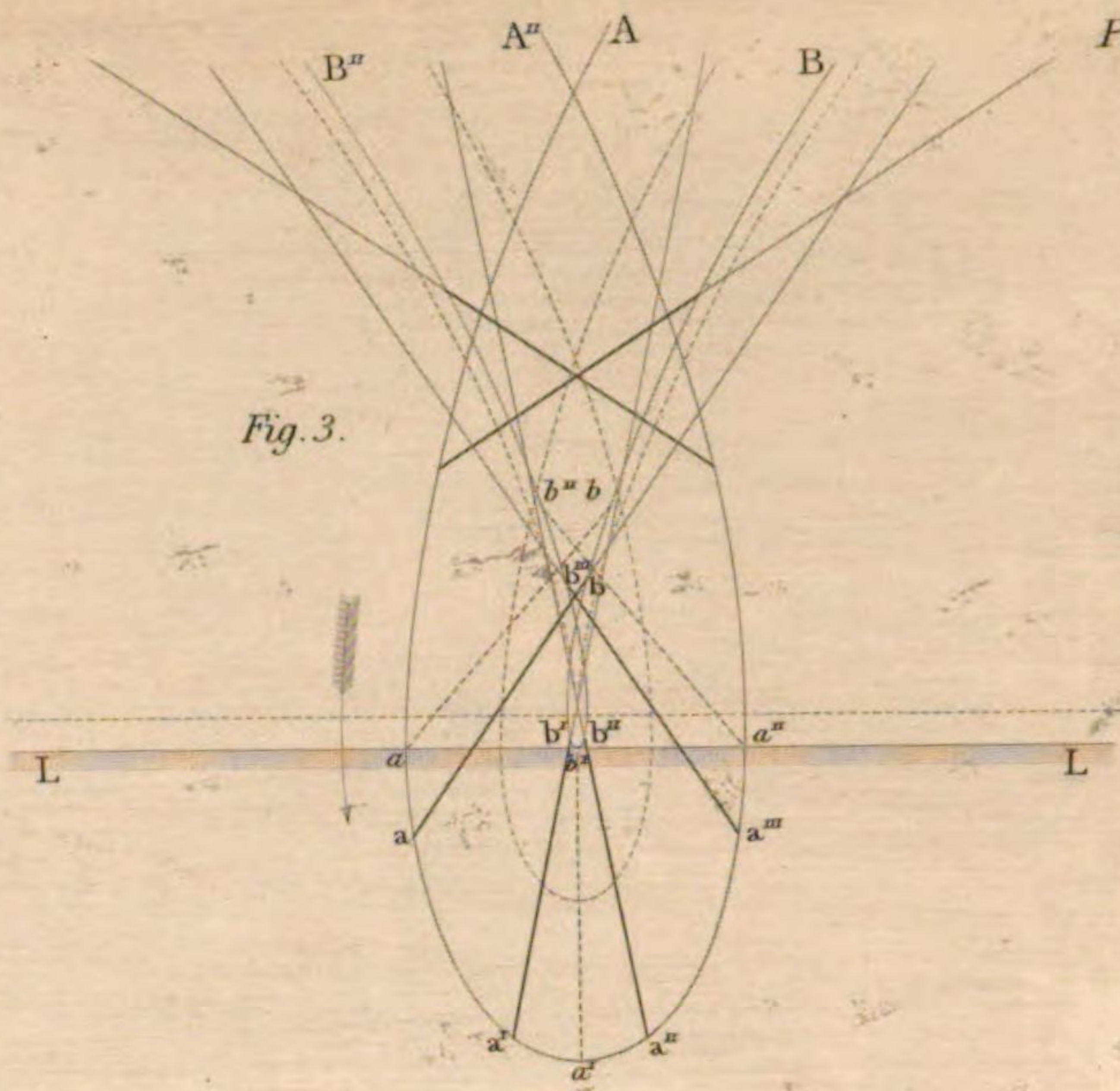


Fig. 1.

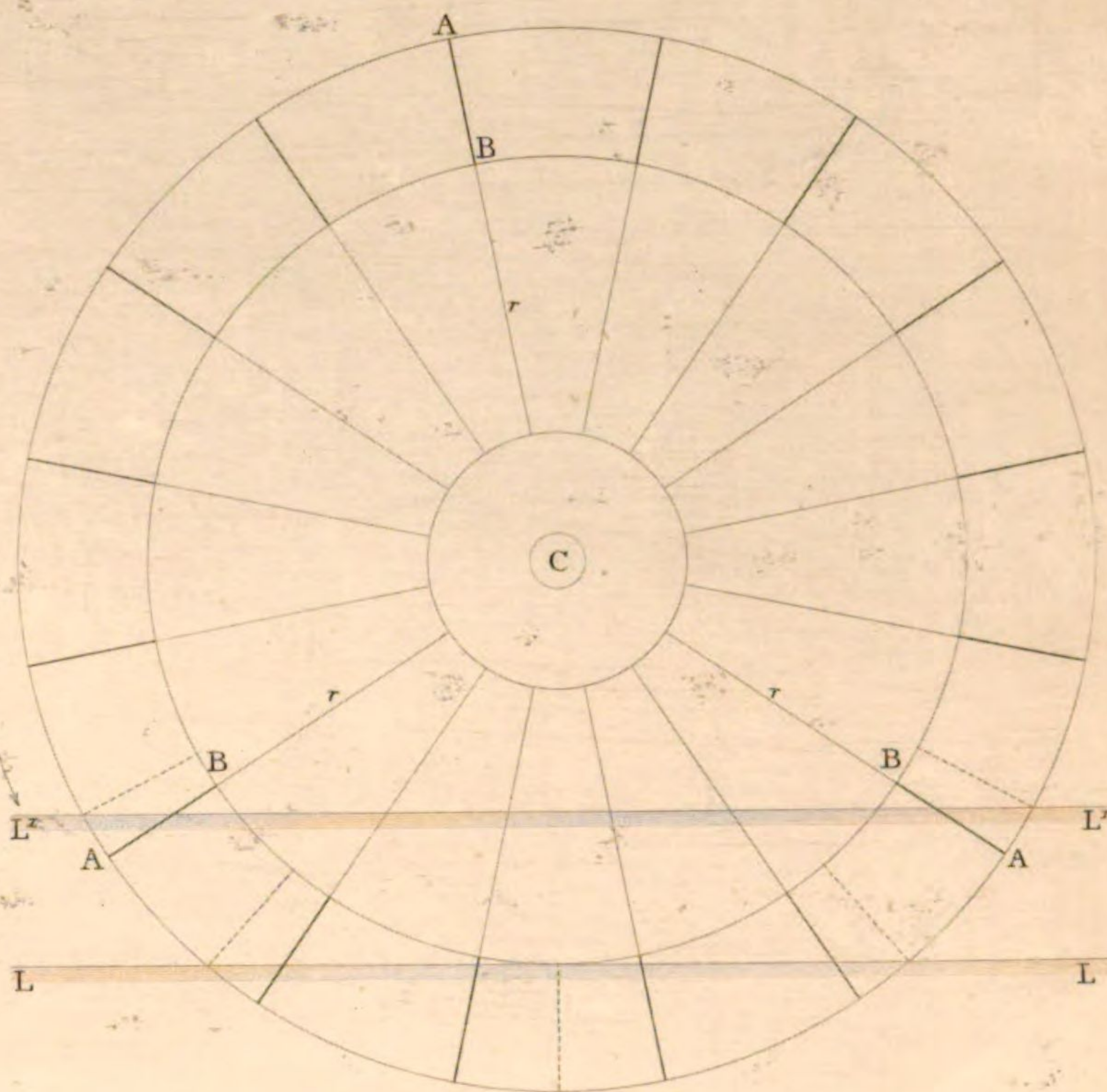


Fig. 5.

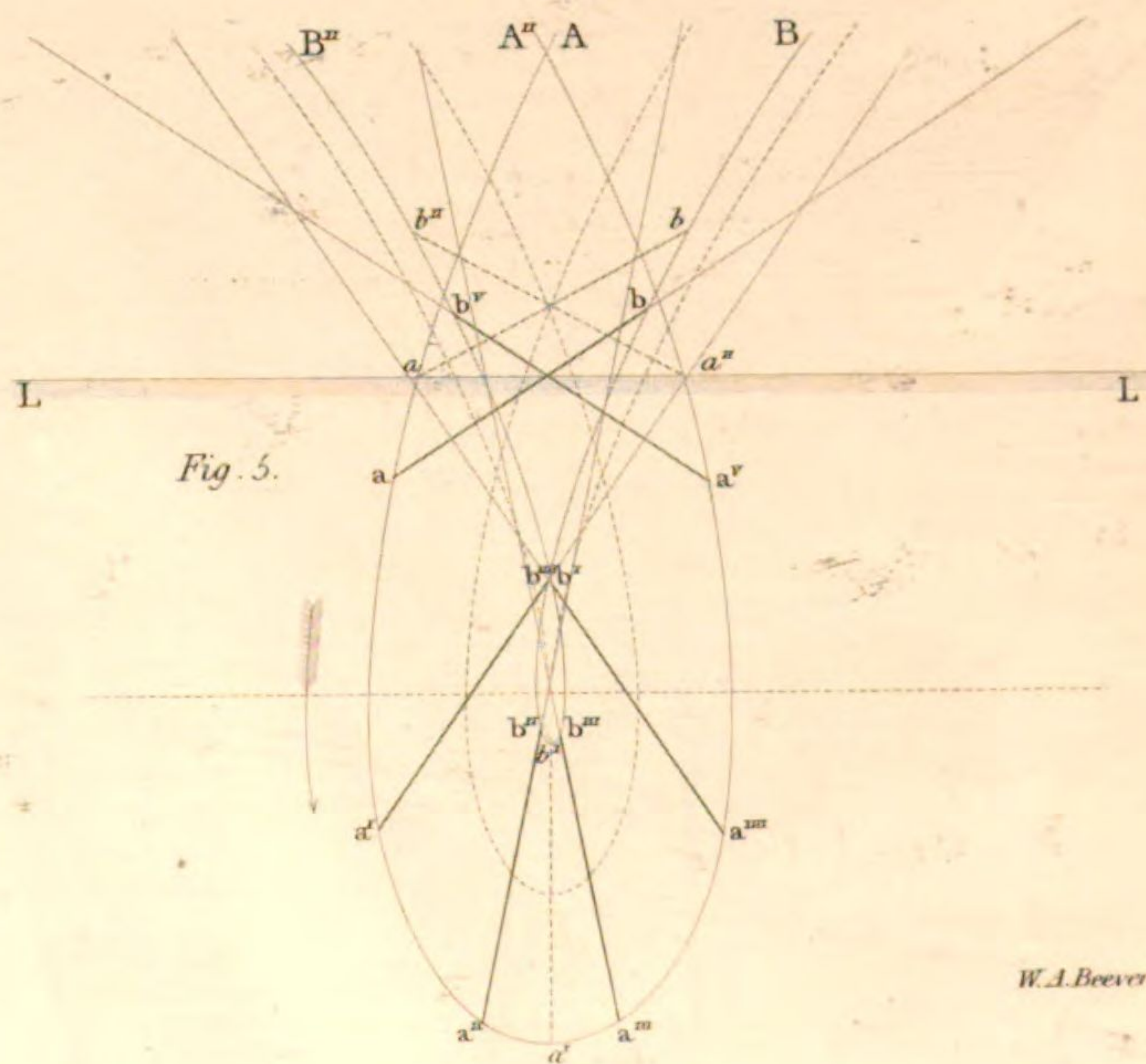


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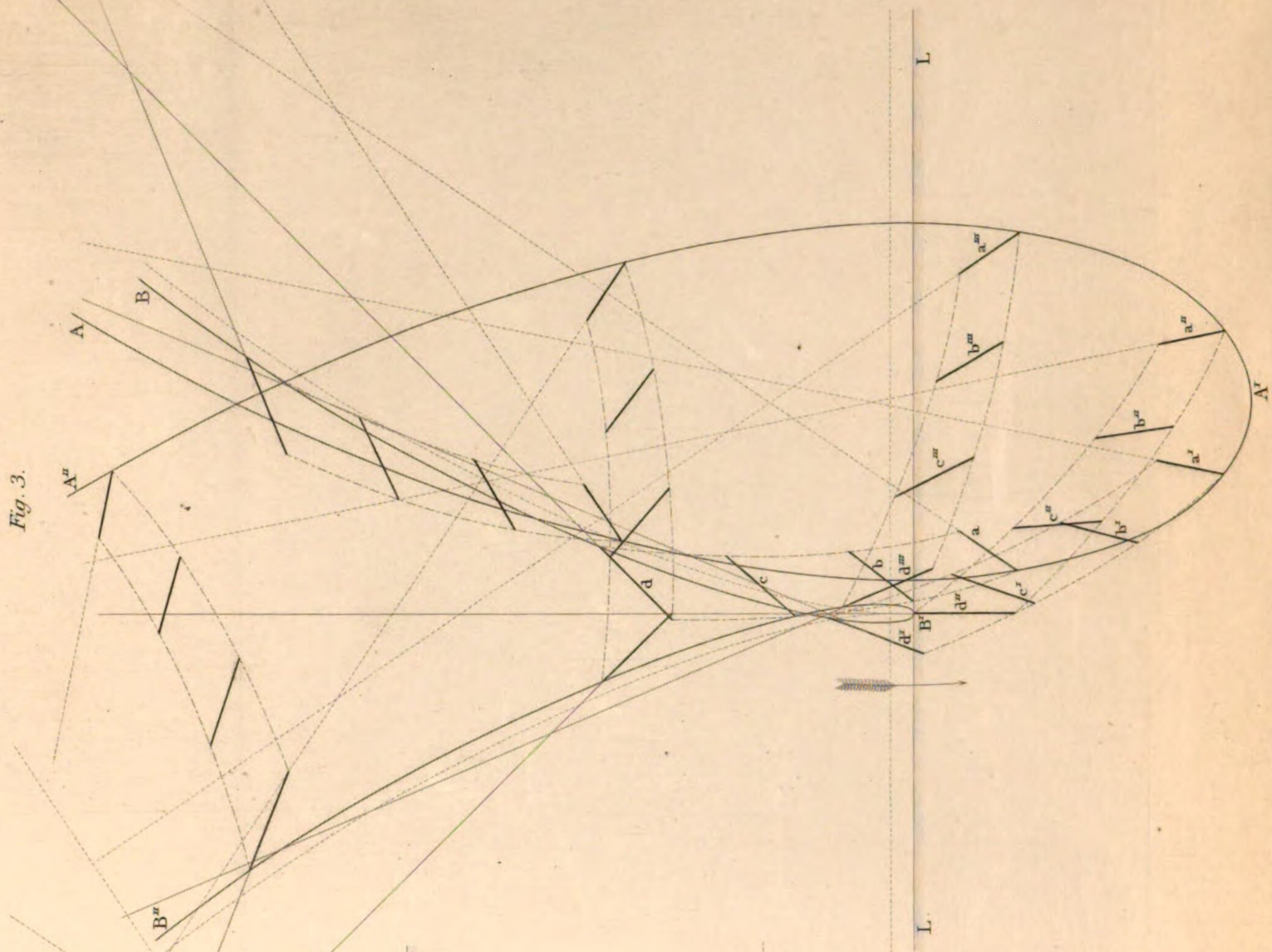


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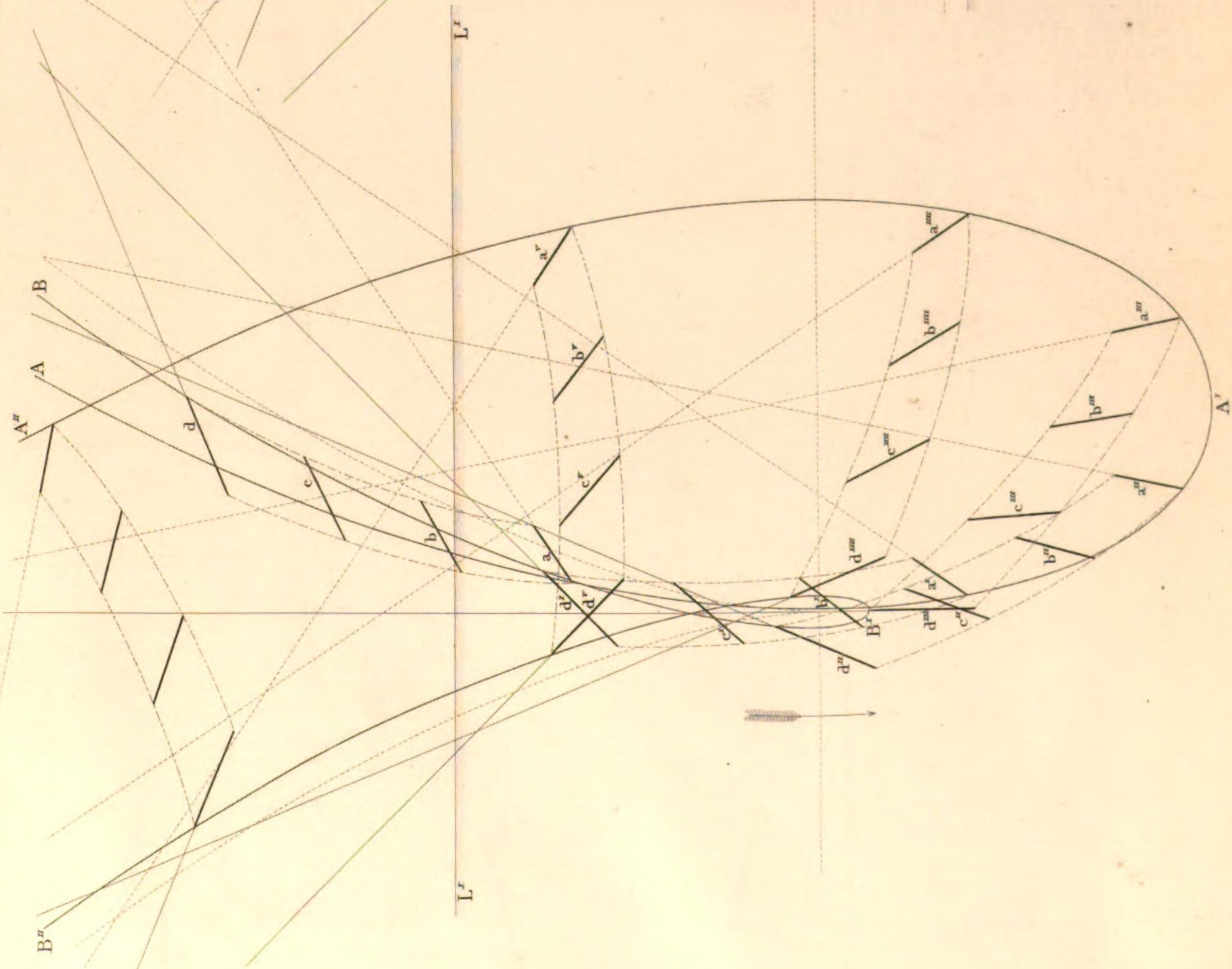


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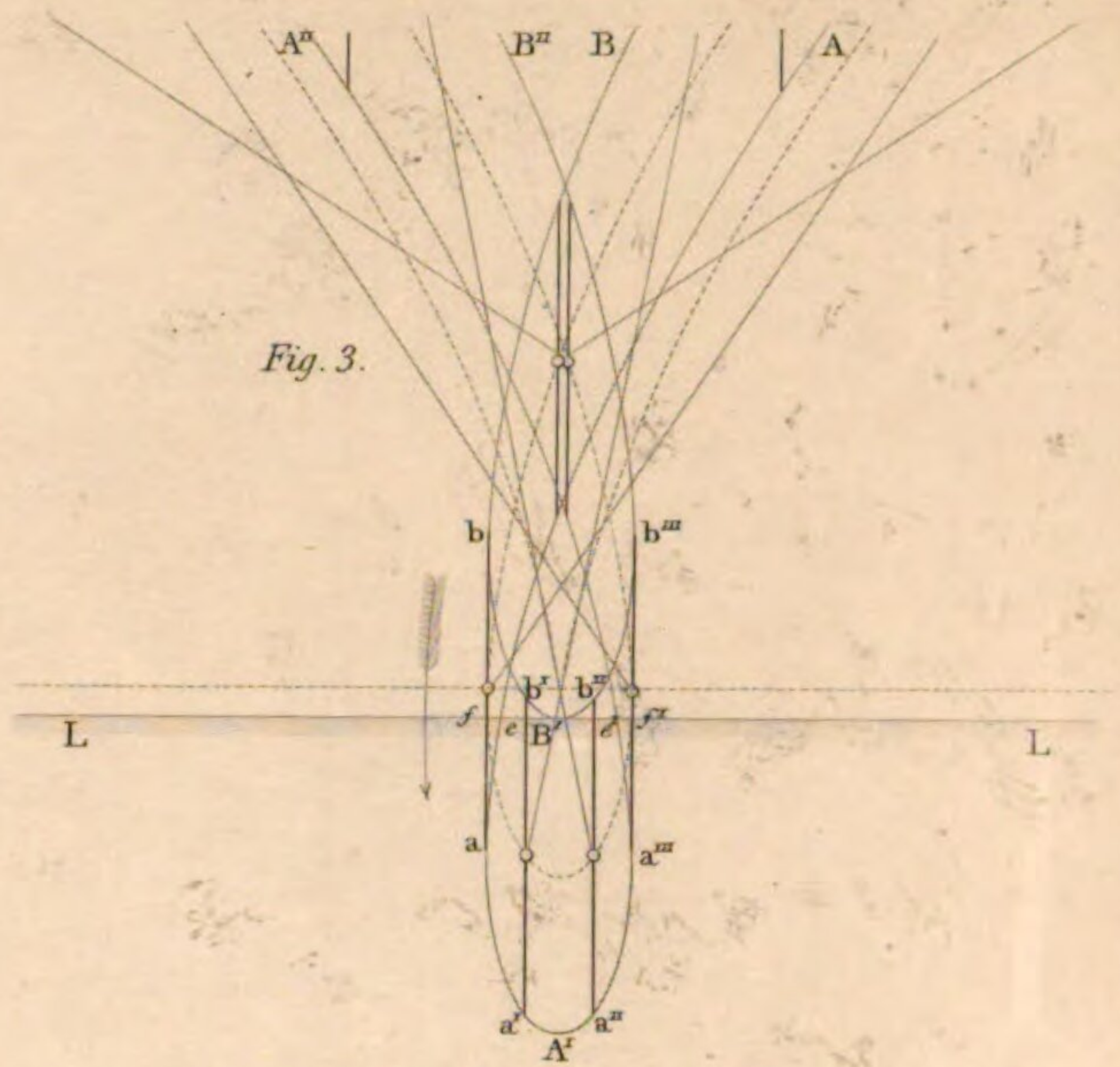


Fig. 1.

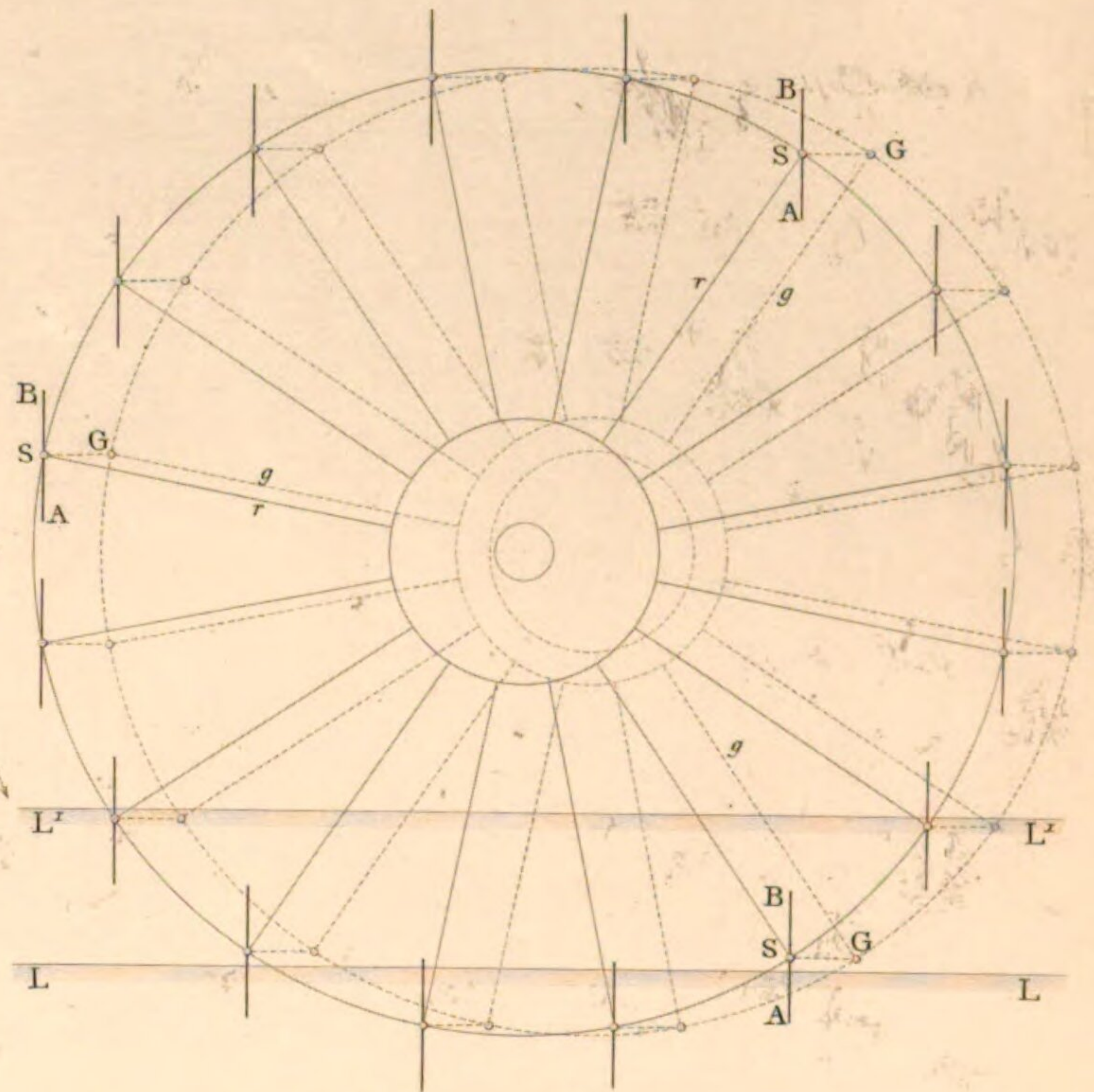
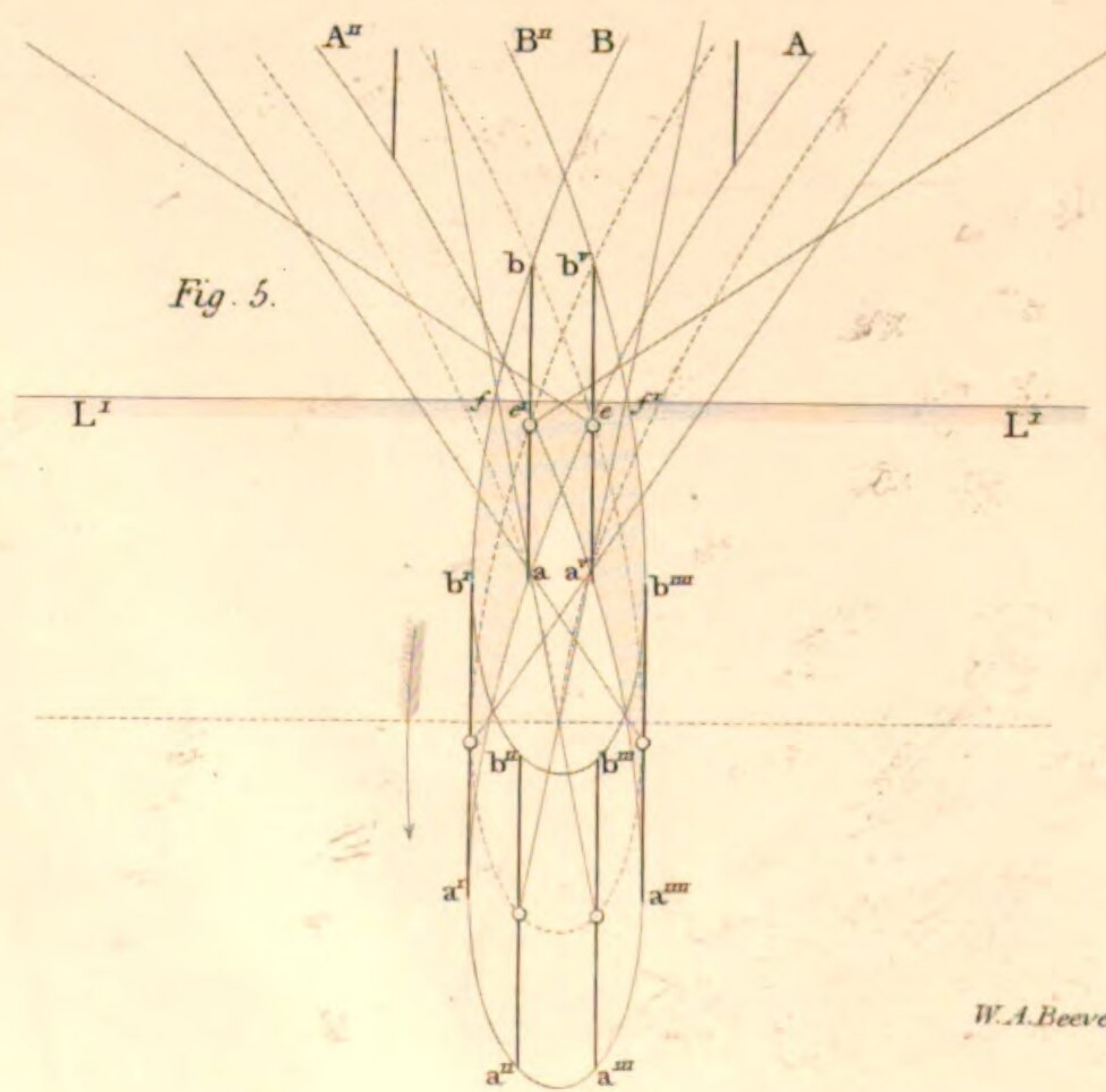


Fig. 5.



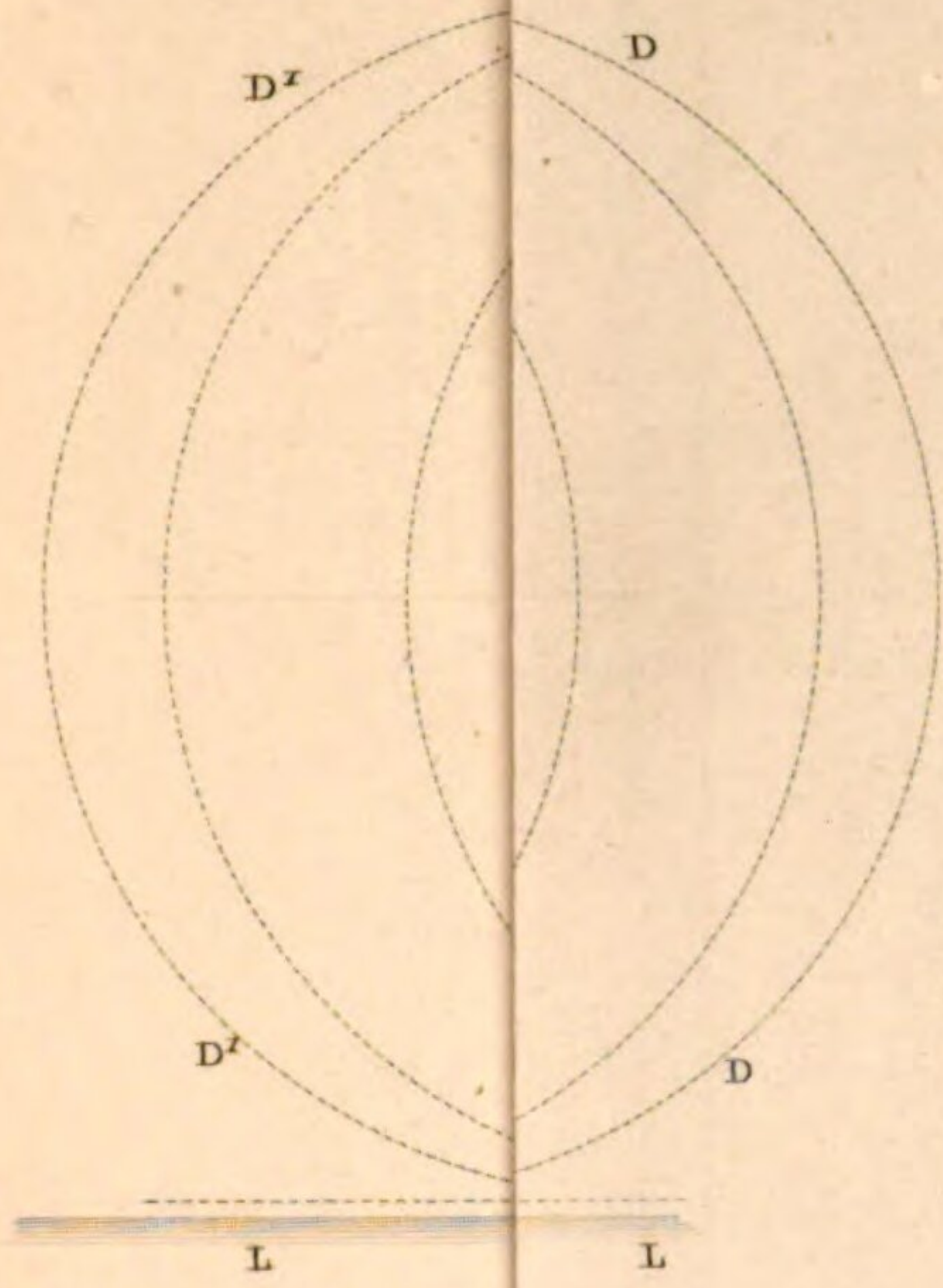


Fig. 1.

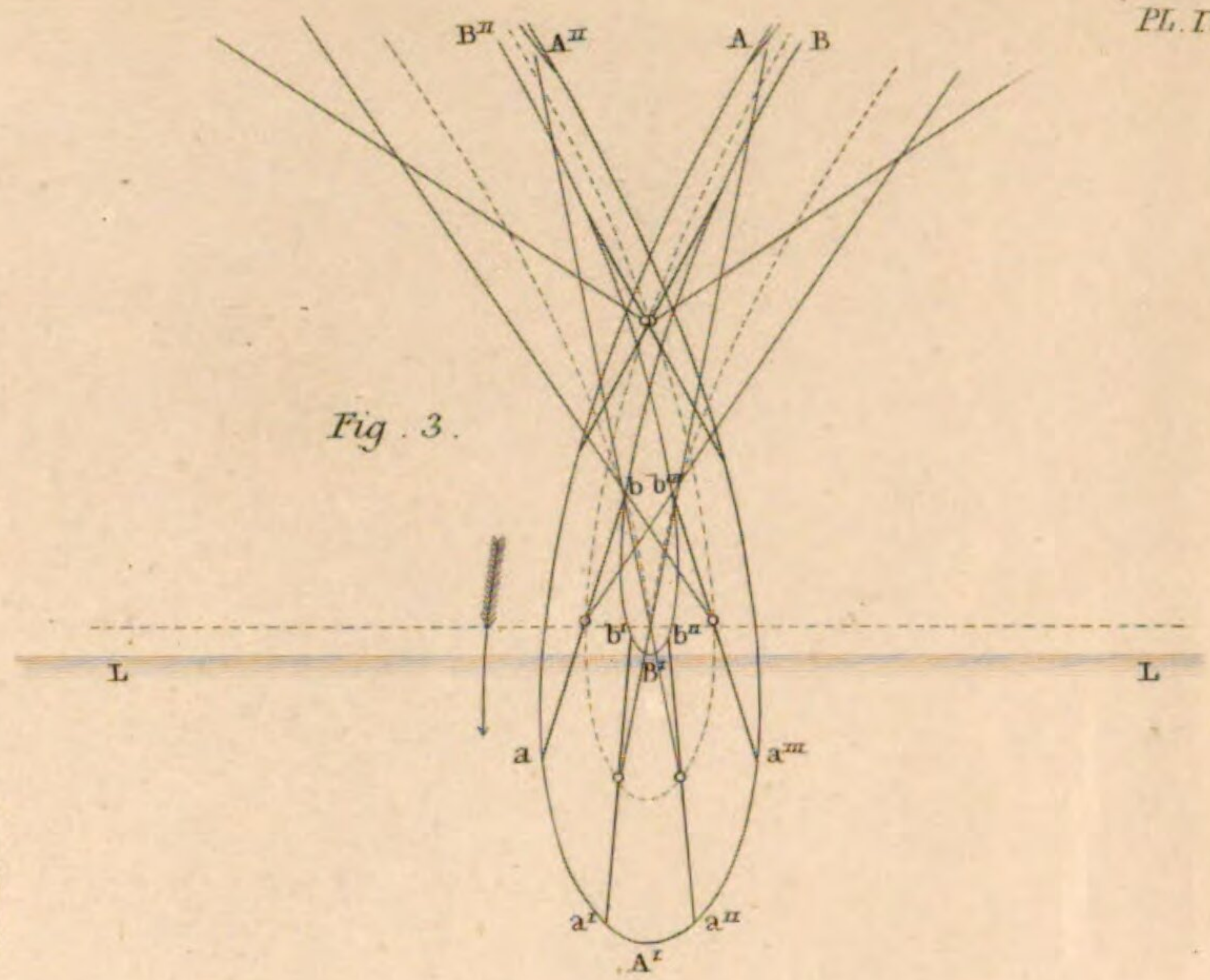
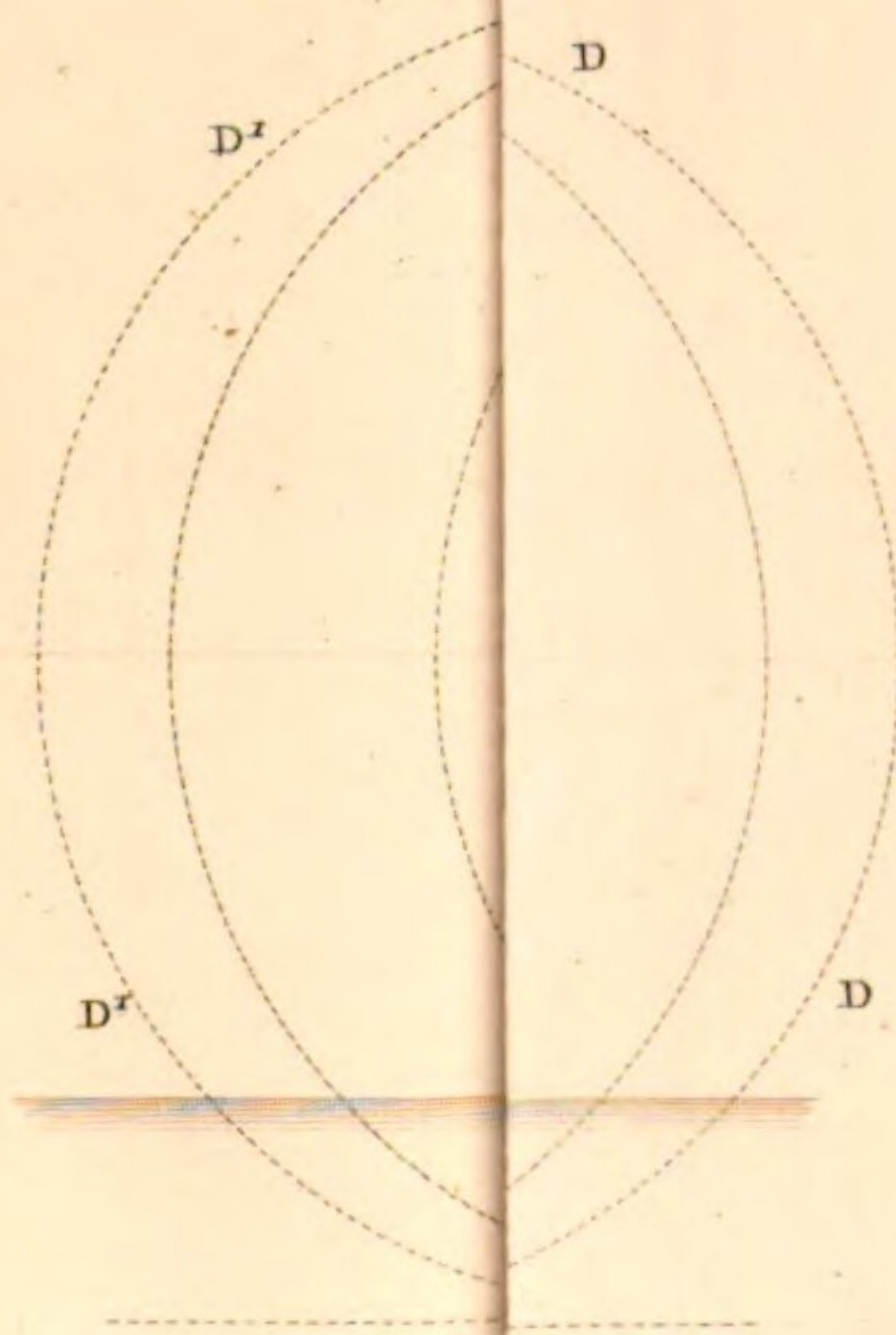


Fig. 3.

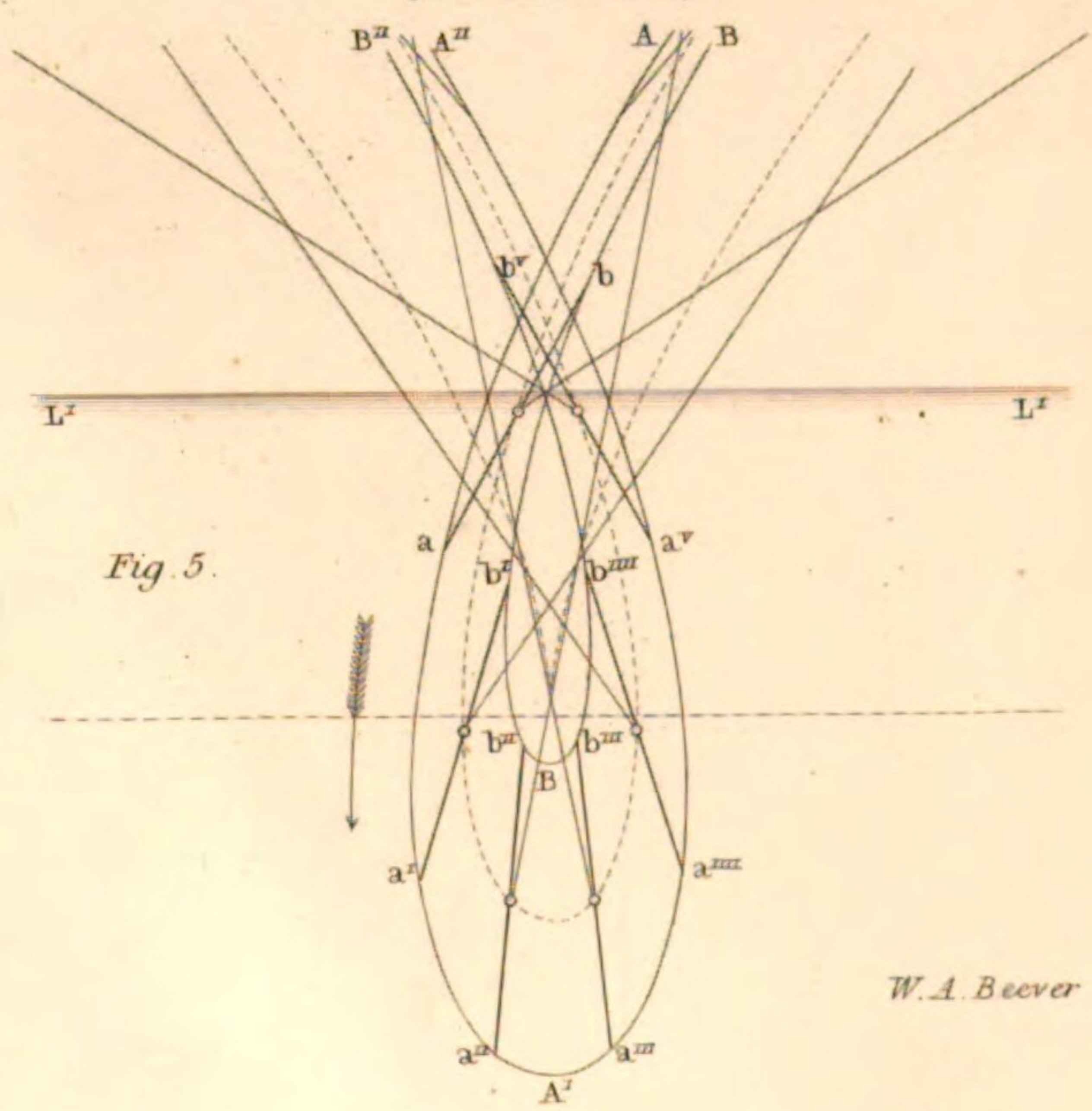
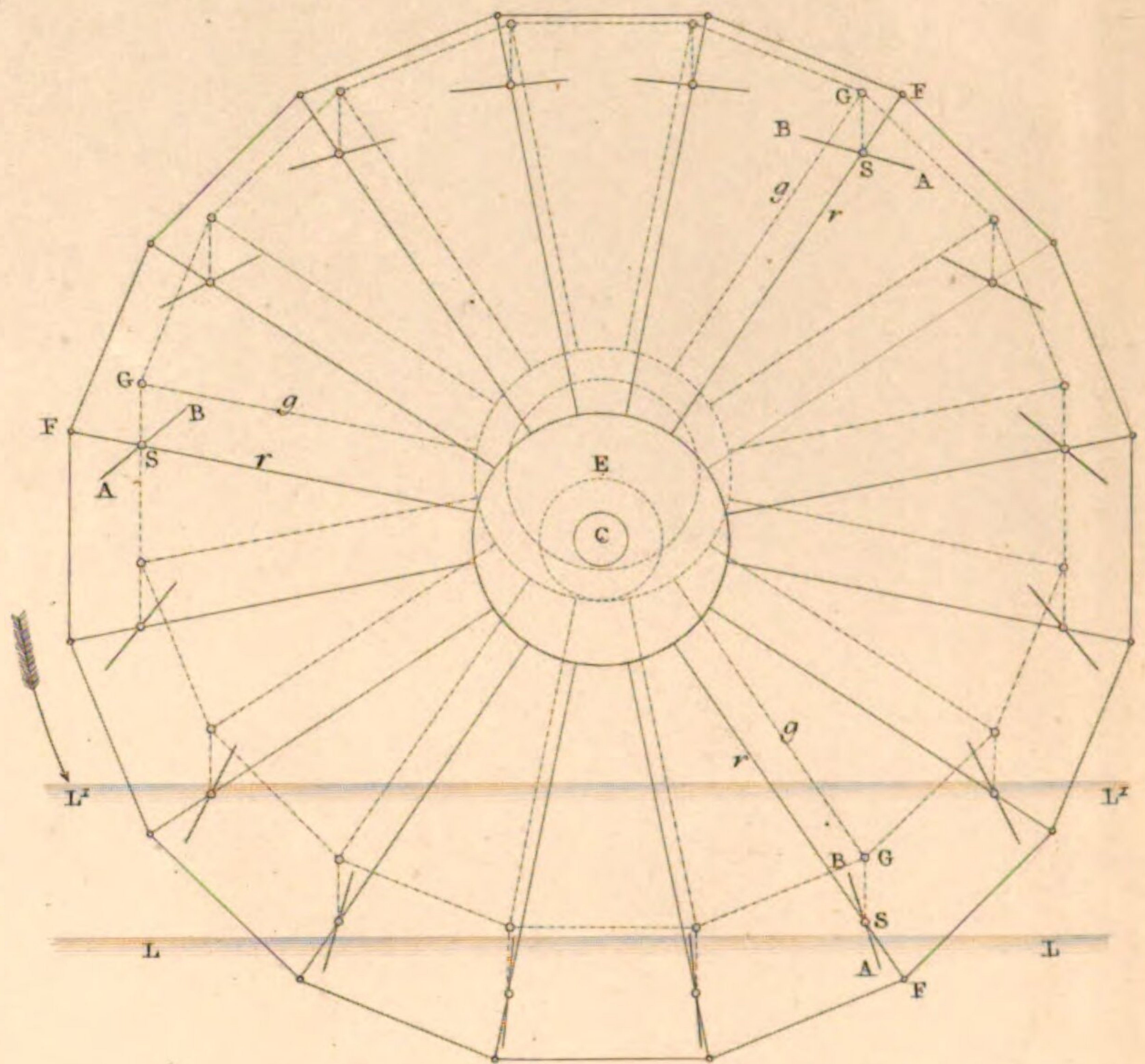


Fig. 5.

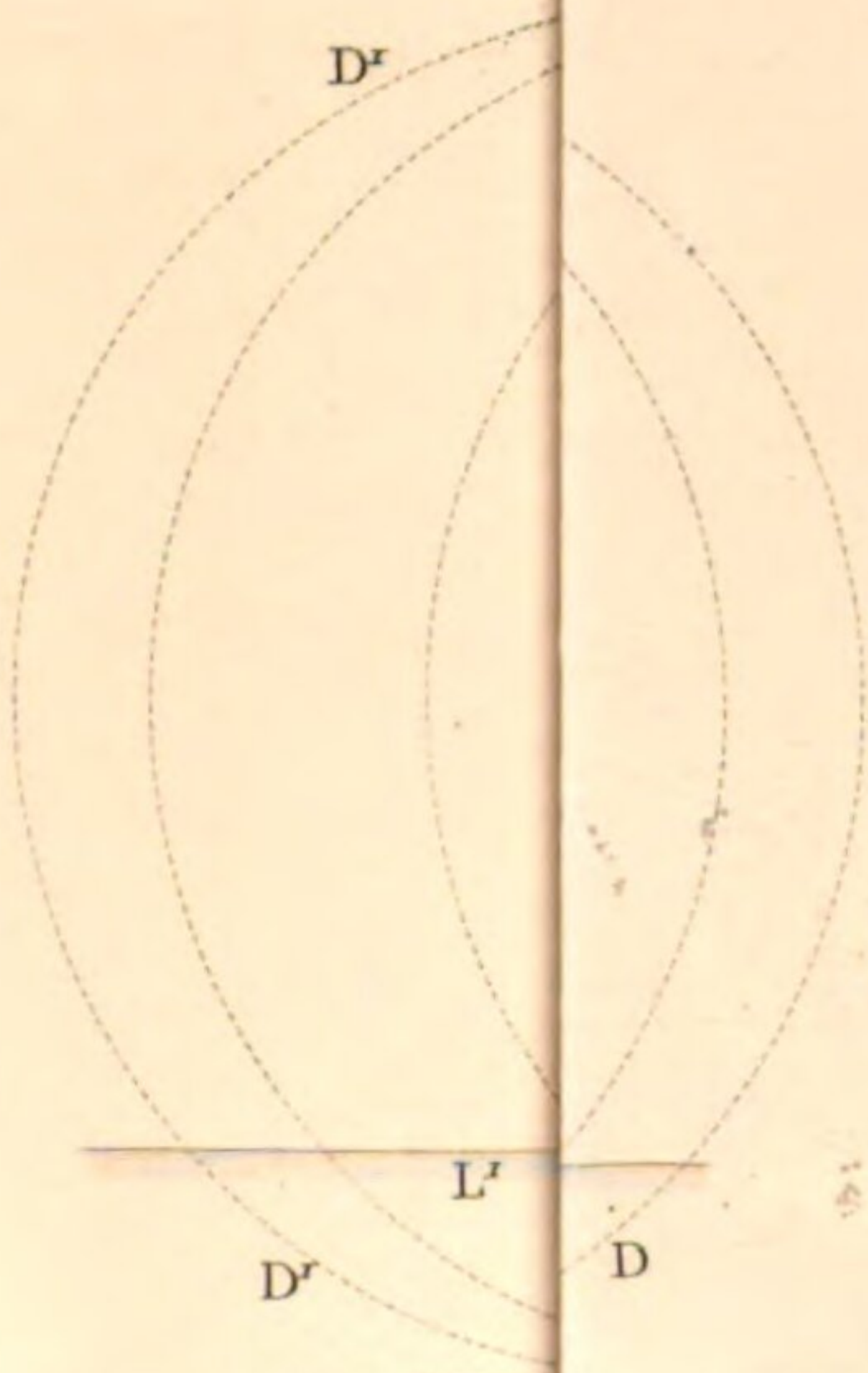
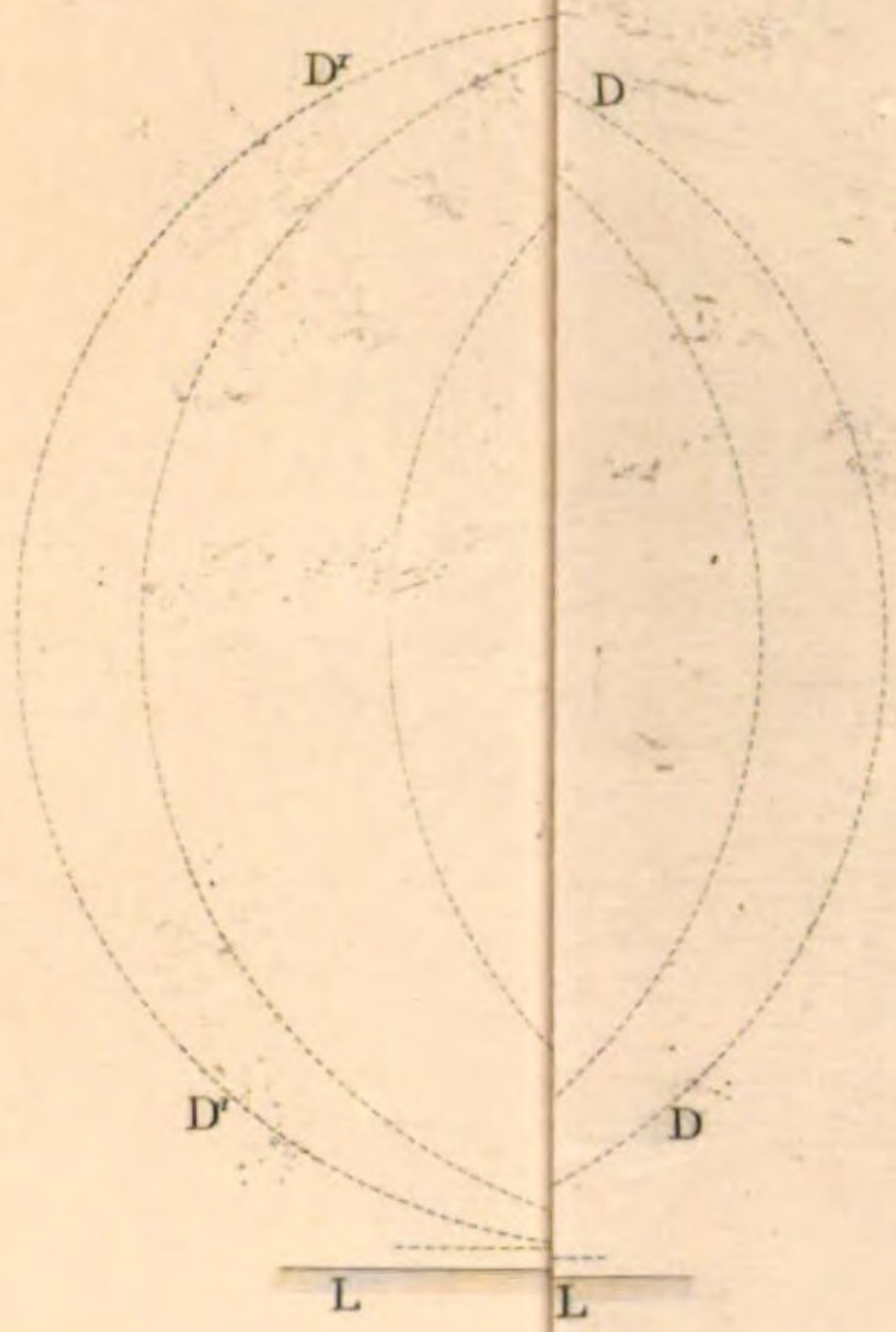


Fig. 1.

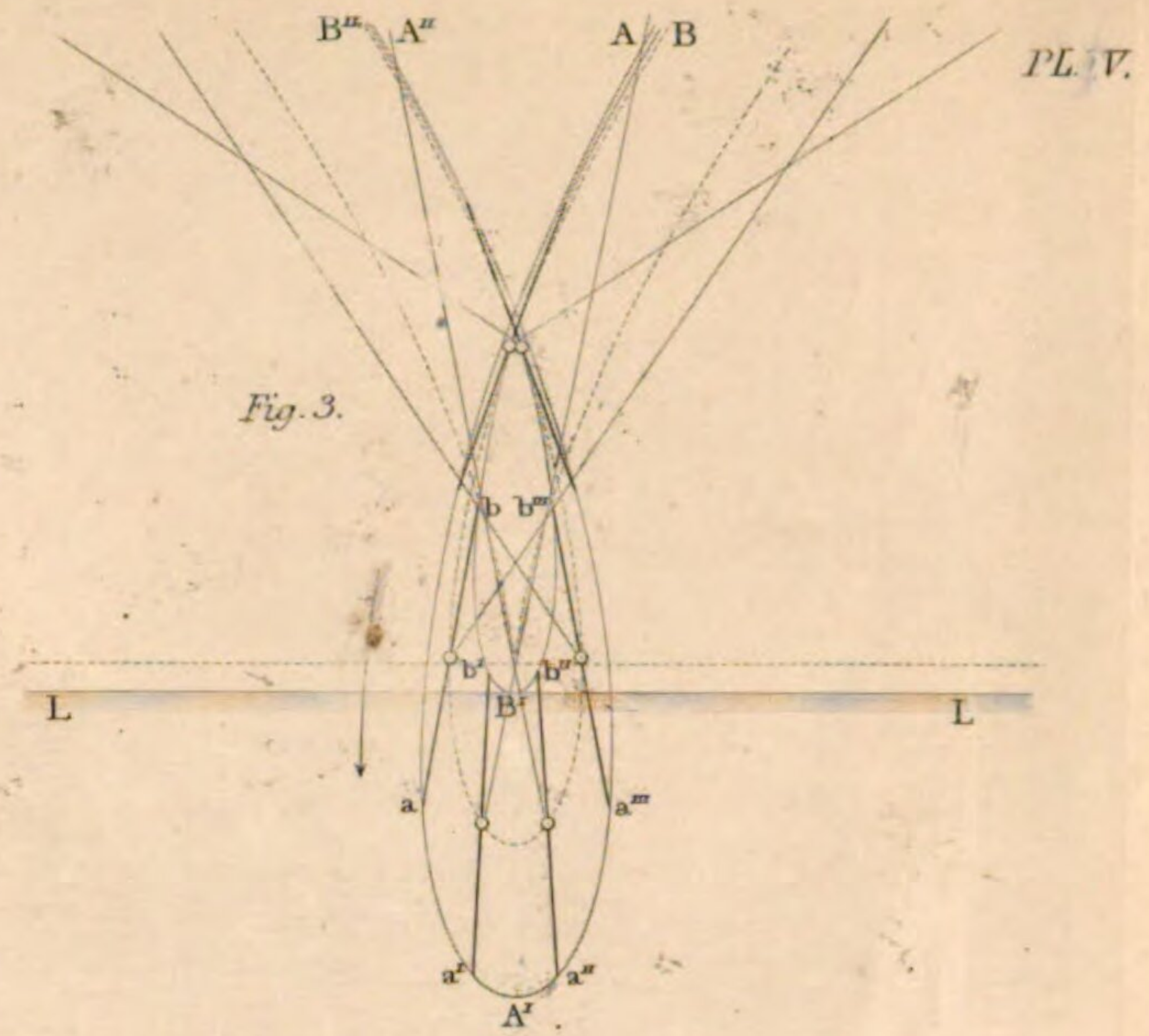


Fig. 3.

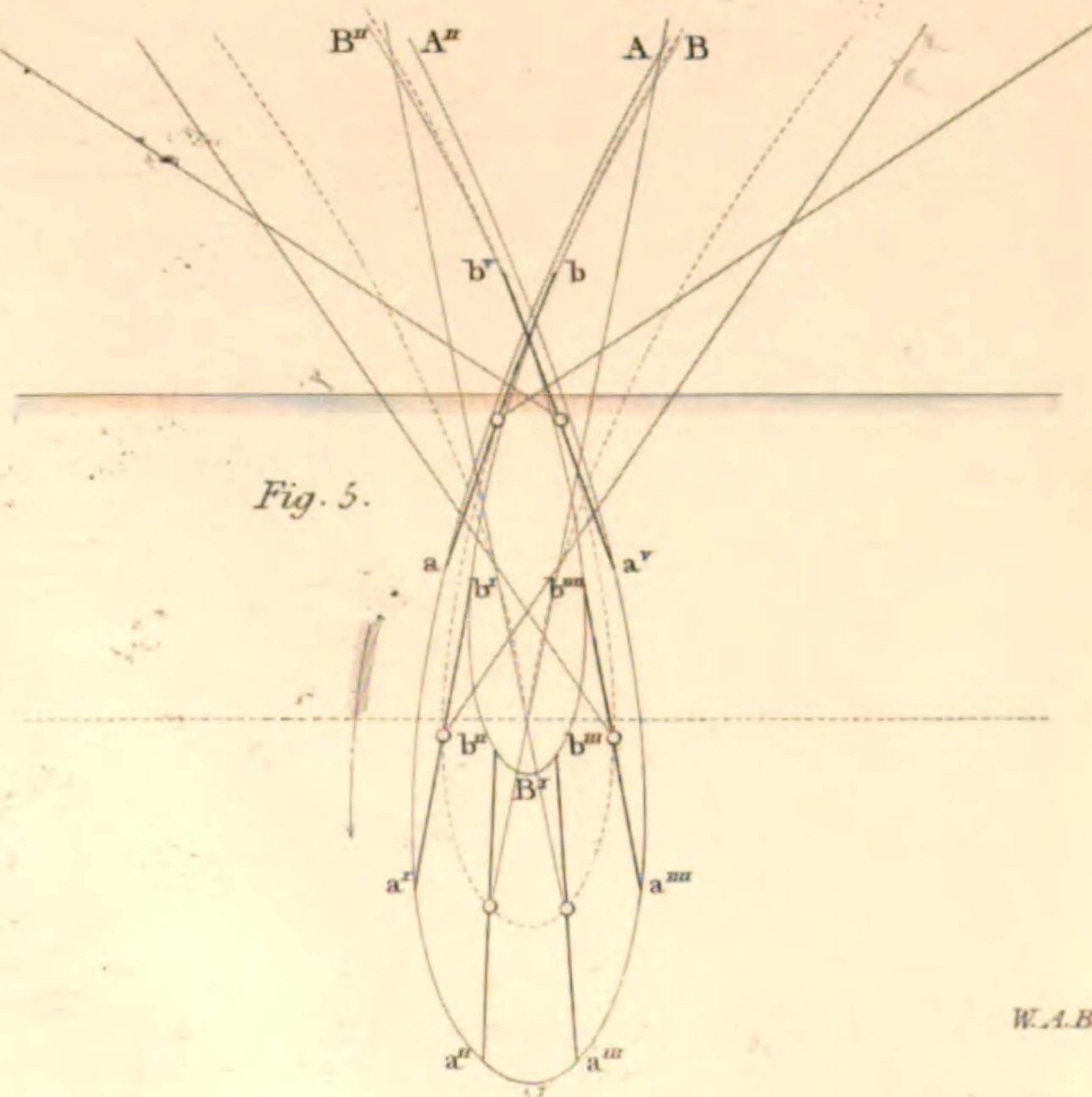
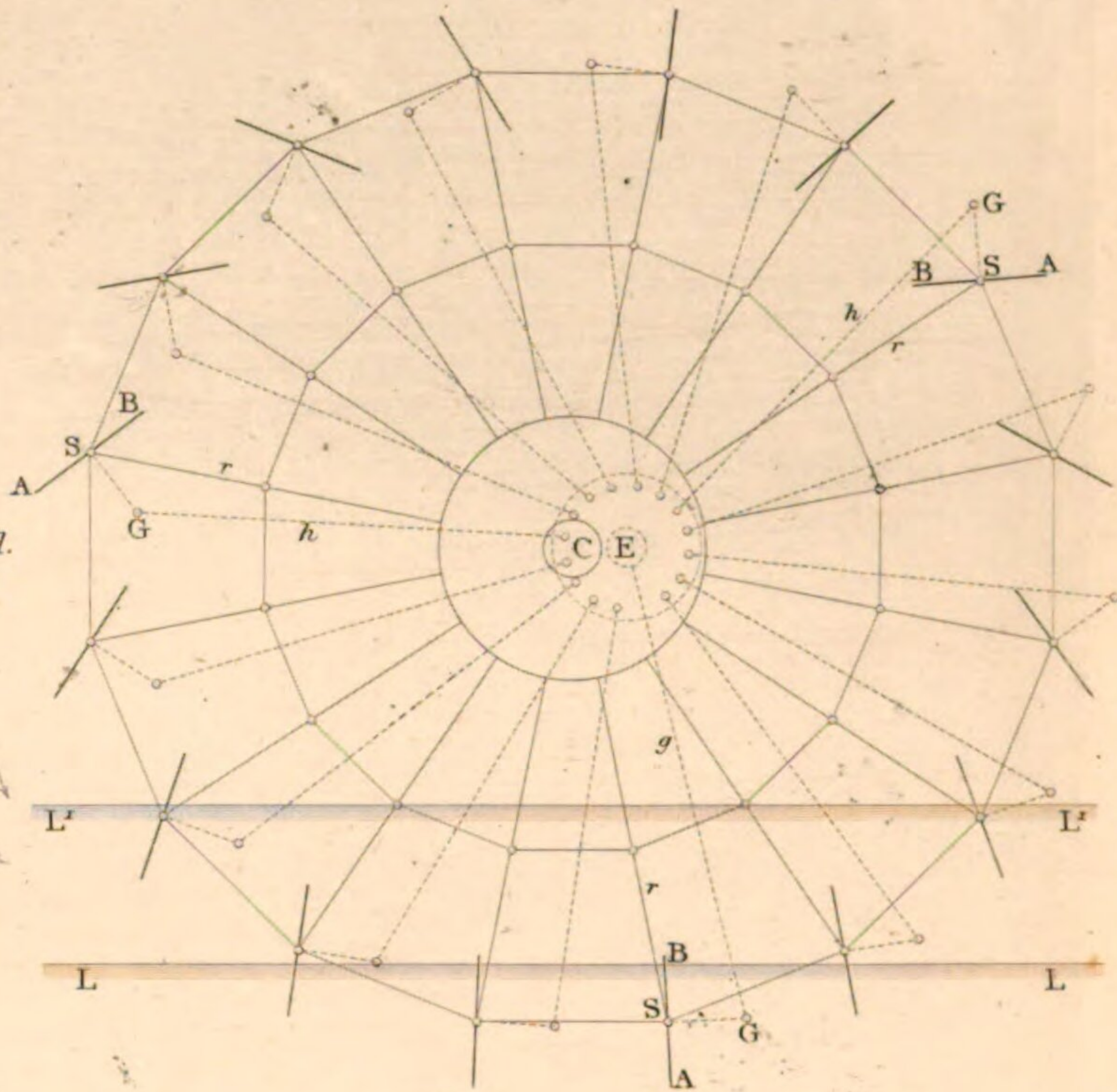


Fig. 5.

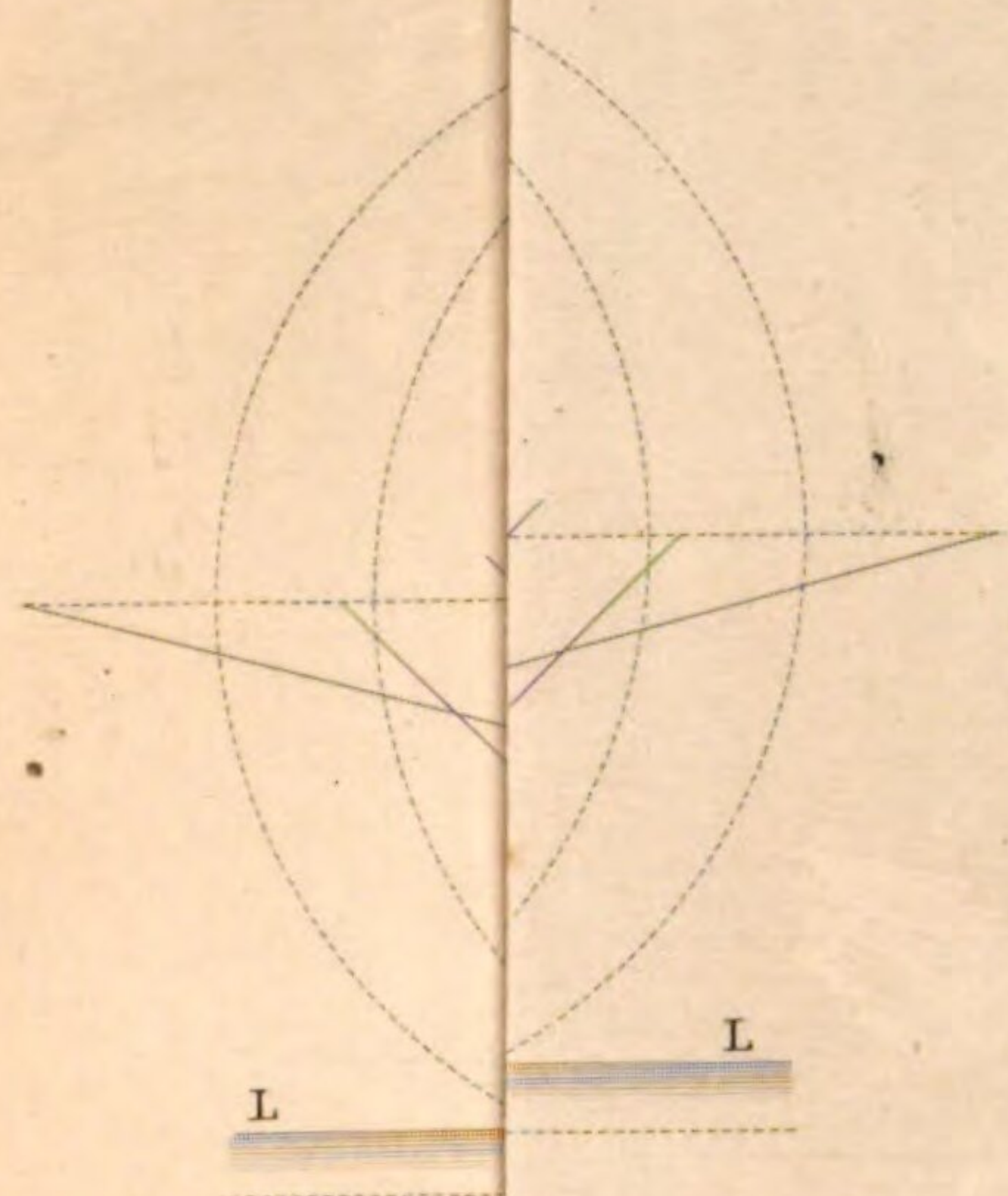
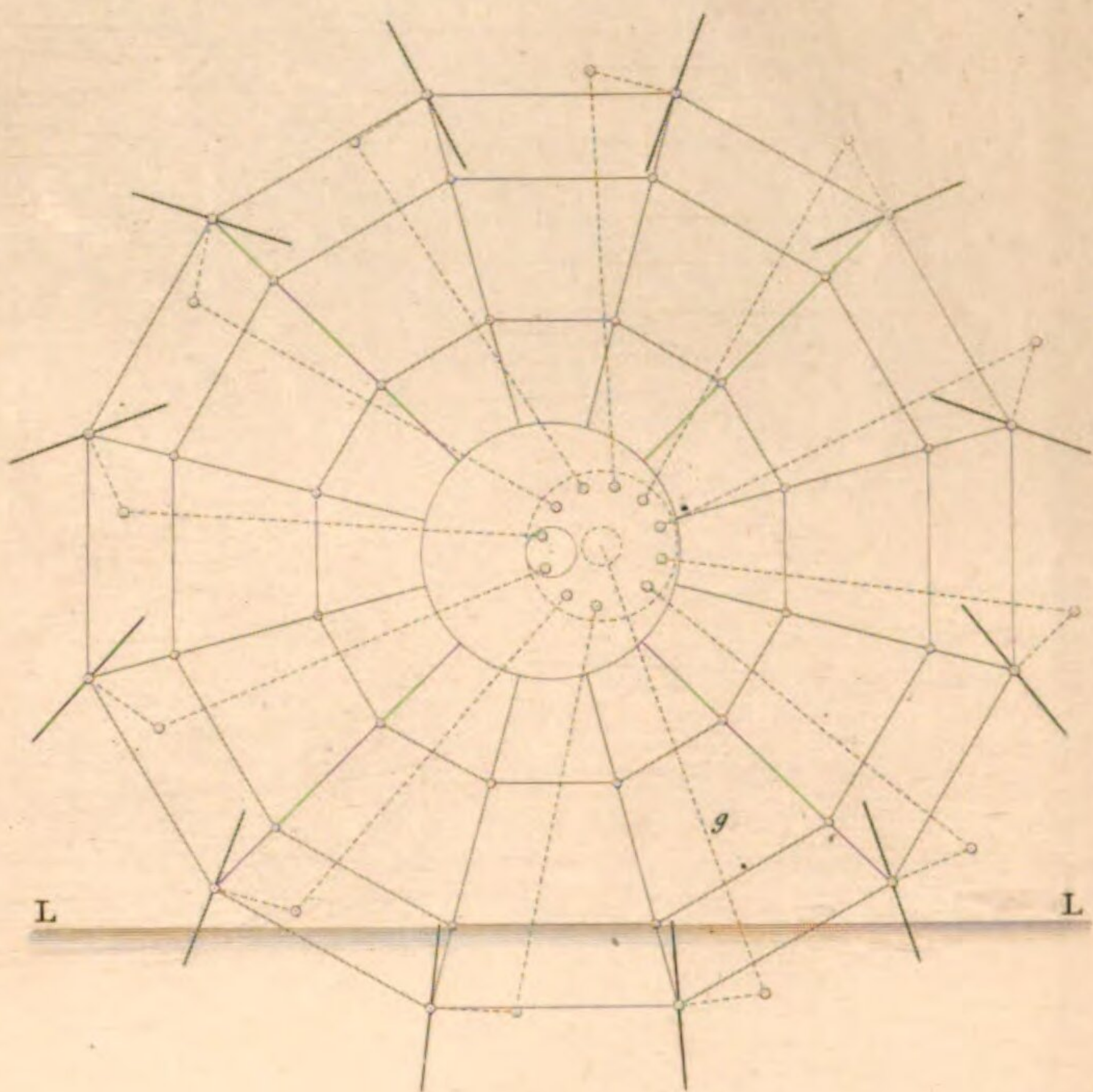
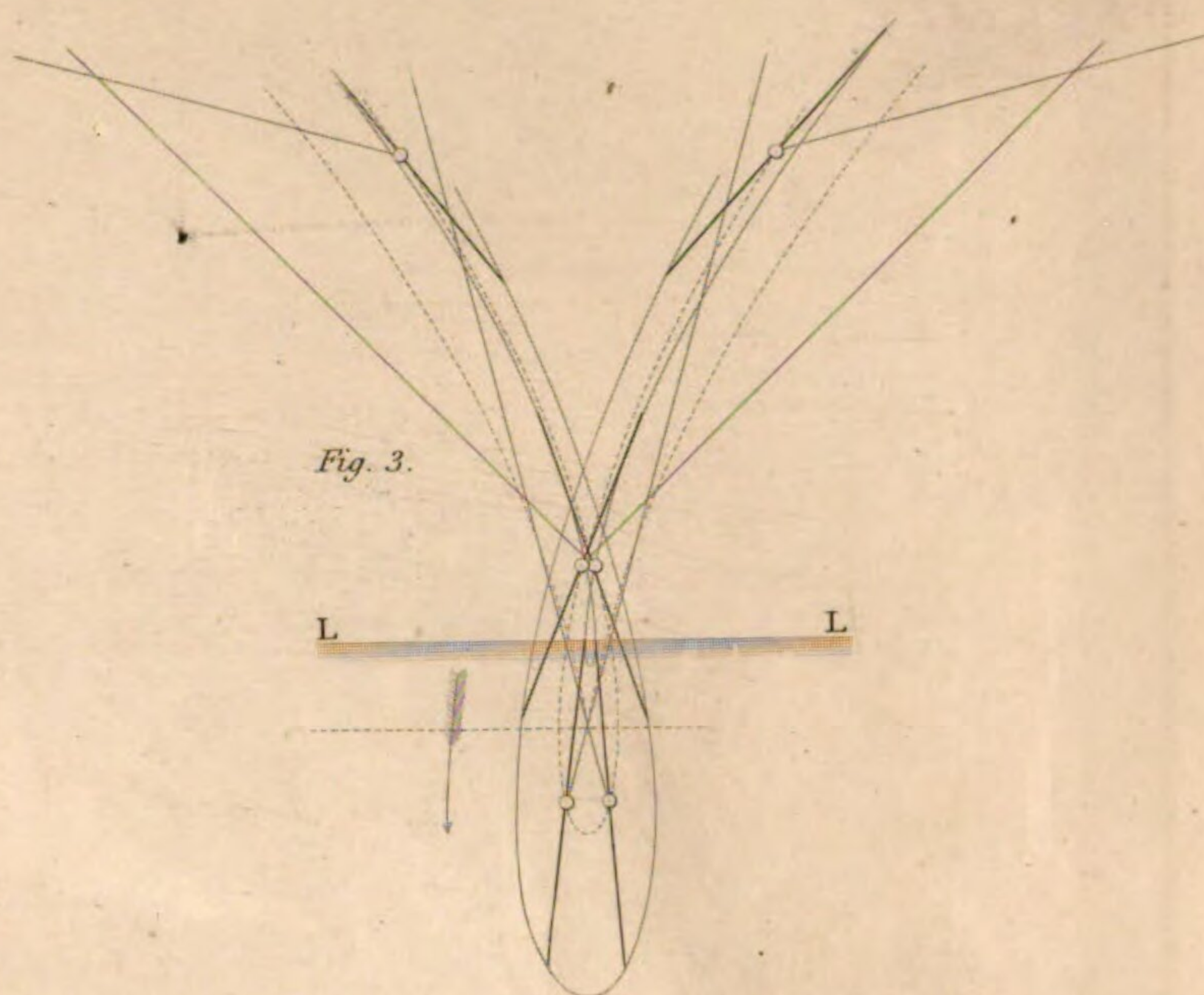
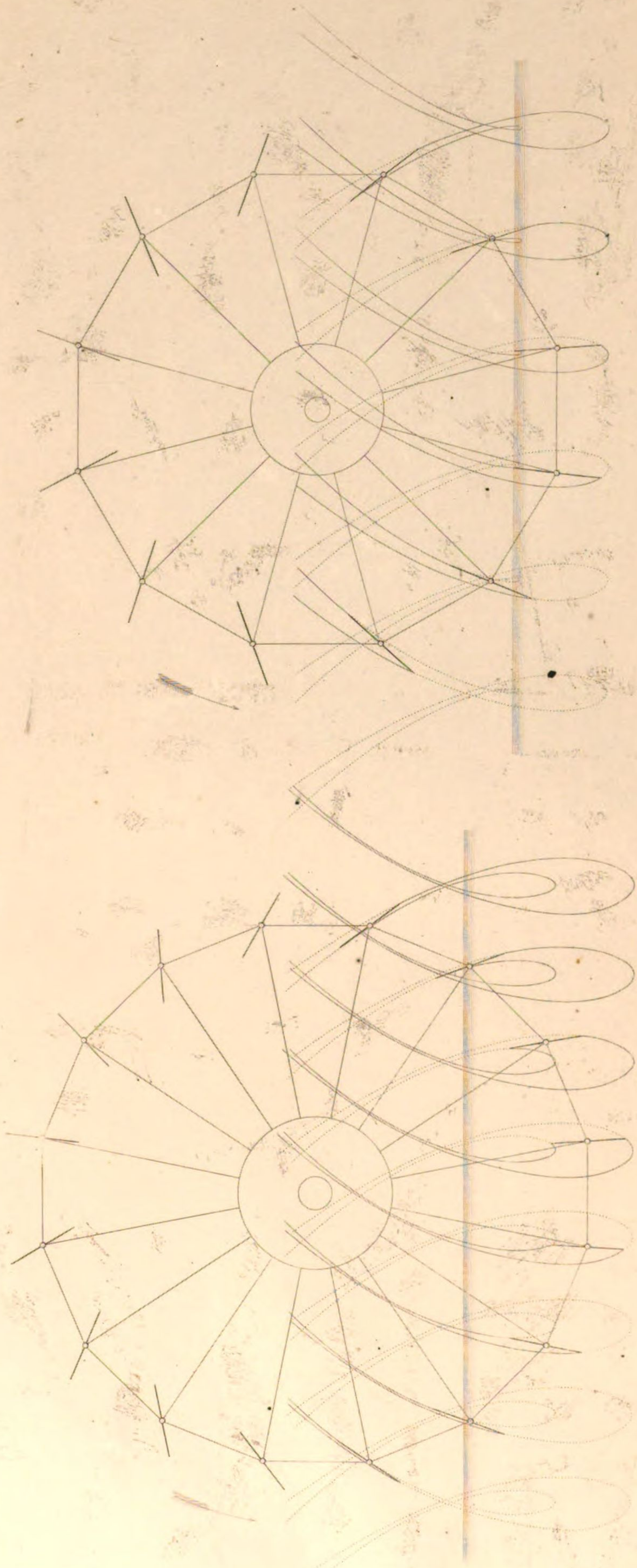
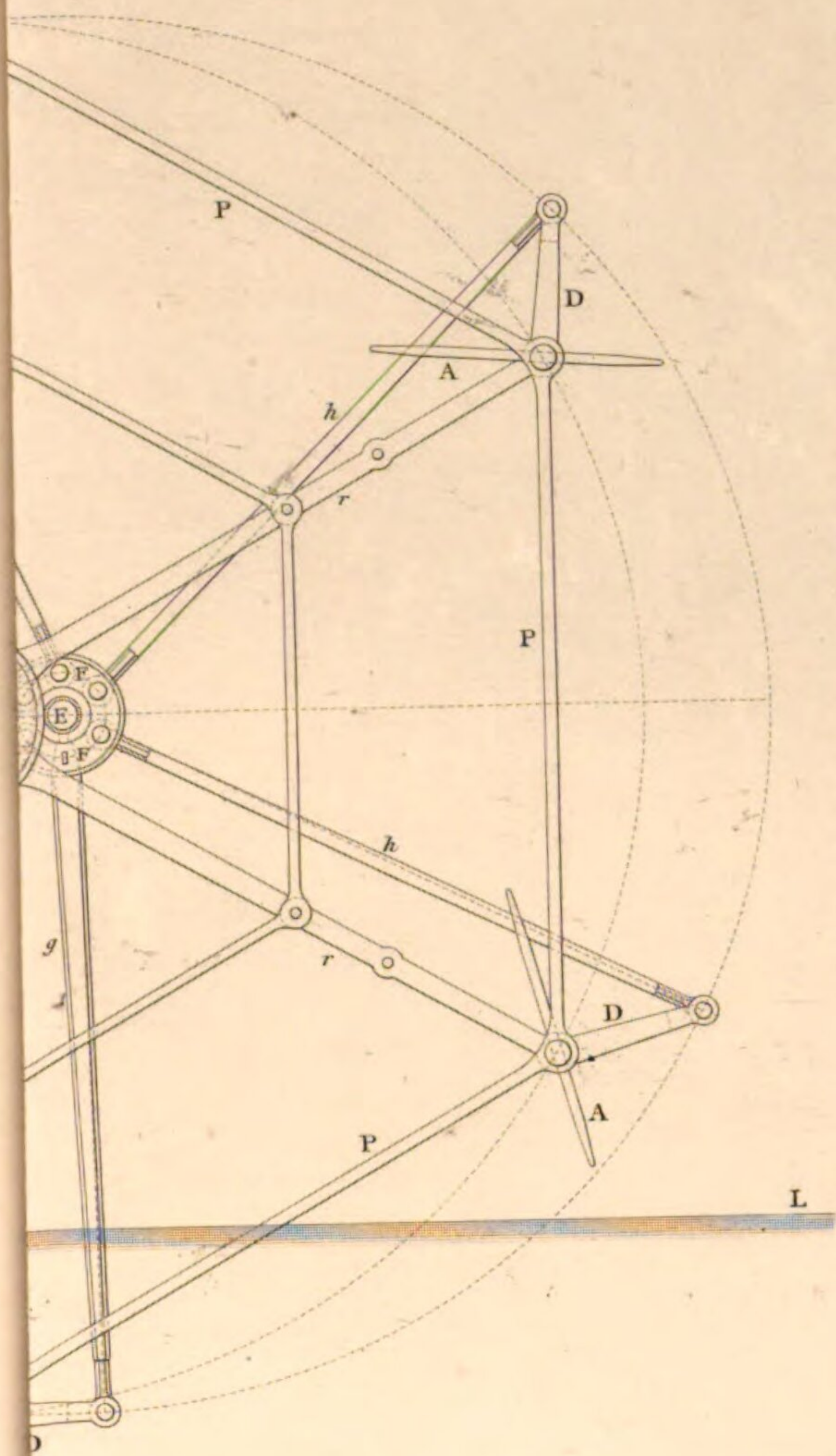


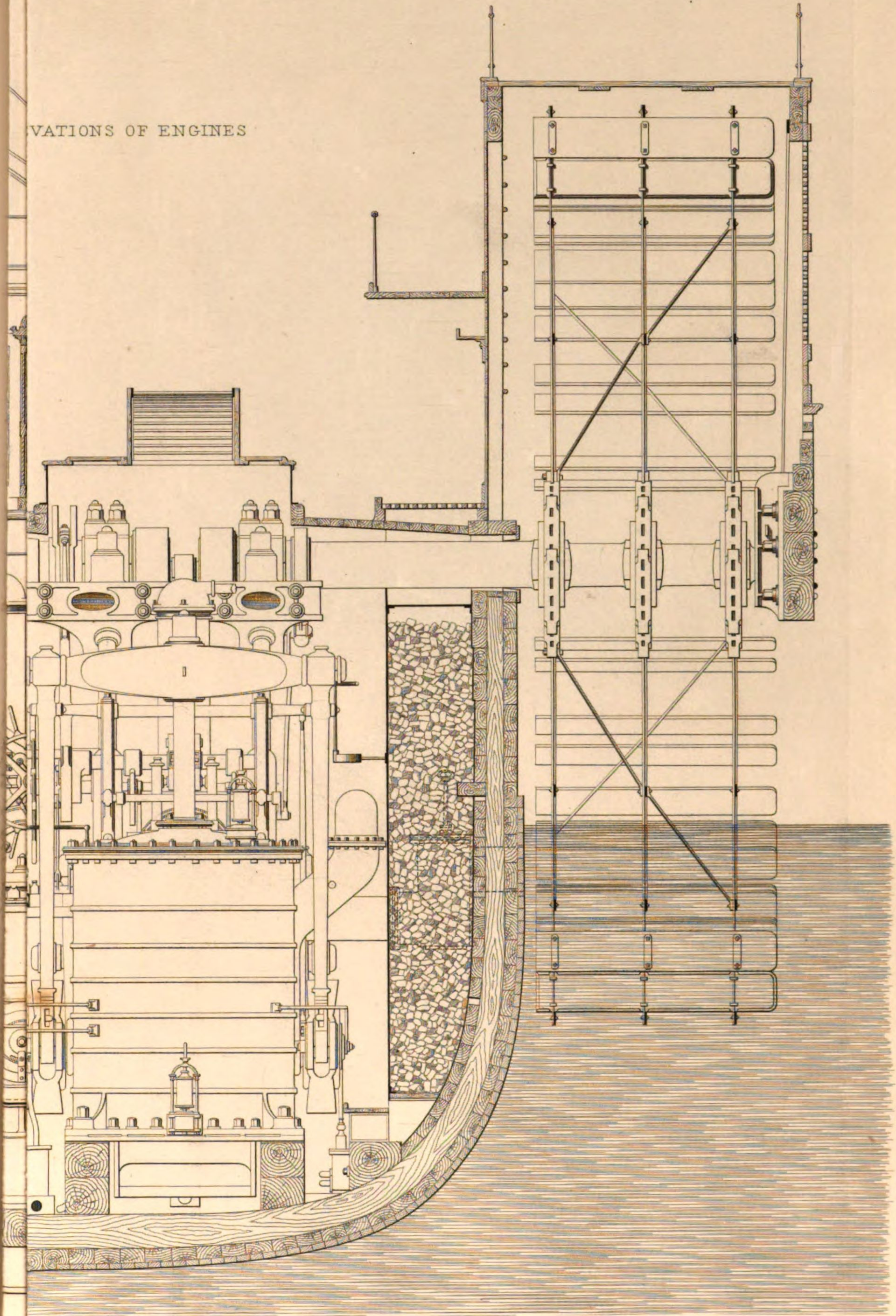
Fig 1.







VATIONS OF ENGINES



GLOSSARY OF TERMS

TERMS USED

ENGINE AND BOILERS

WATER

FRENCH AND SPANISH TRANSLATIONS

Water (Fr. is *eau*) this surrounds the bottom of the chimney, to prevent the deck. Sp. *caja de agua, chapa.*

Water leading from the top of the hot well through the ship's side, for the condensed vapor pumped by the air-pump. Sp. *cabo de agua.*
Water required to maintain the vacuum in the condenser by withdrawing the and uncondensed vapor. Sp. *bomba de agua, bomba de vapor.*

Water in a motor to be pumped manually.
Water in the tubes hung in the coal-burner from the deck and filled with water, maintaining the temperature of the coils by a thermometer as a precaution.

Water (Fr. *biere de vapeur*)
Water in the form of a ring encircling an inner cylinder which is perforated with the arrangement is sometimes adopted to give length of connection and to within the inner cylinder.

Water underneath the fire-bars of the furnace, where the water collects.

Water (Fr. *machine à vapeur atmosphérique*) a condensing engine in which the water is used during the expansion only, the return stroke being performed by the action of a vacuum. Sp. *maquina atmosférica.*
Water (Fr. *machine à vapeur*) a condensing engine in which the water is used during the expansion only, the return stroke being performed by the action of a vacuum. Sp. *maquina a vapor.*

Water (Fr. *machine à vapeur*) a condensing engine in which the water is used during the expansion only, the return stroke being performed by the action of a vacuum. Sp. *maquina a vapor.*

GLOSSARY OF TERMS

CONNECTED WITH

MARINE ENGINES AND BOILERS,

WITH

FRENCH AND SPANISH TRANSLATIONS.¹

Air casing, of thin sheet iron, (Fr. la chemise :) this surrounds the bottom of the chimney, to prevent the radiation of heat to the deck. Sp. caja de aire, chaqueta.

Air-furnace, see *Blast-furnace*.

Air-pipe, a small copper pipe leading from the top of the hot-well through the ship's side, for the discharge of the air and uncondensed vapour pumped by the air-pump. Sp. tubo de aire.

Air-pump, (Fr. la pompe à l'air,) required to maintain the vacuum in the condenser by withdrawing the condensing water, air, and uncondensed vapour. Sp. bomba neumática, bomba de aire.

Air-pump bucket, Sp. émbolo ó mortero de la bomba neumática.

Air-tubes are small wrought-iron tubes hung in the coal-boxes from the deck and filled with water, for the purpose of ascertaining the temperature of the coals by a thermometer, as a precaution against spontaneous combustion.

Angle-iron, (Fr. cornière.) Sp. hierro de ángulo.

Annular piston, one made in the form of a ring encircling an inner cylinder which is enclosed within the external one. This arrangement is sometimes adopted to gain length of connecting rod, by causing it to descend within the inner cylinder.

Anvil, (Fr. masse.) Sp. yunque.

Ash-pits, (Fr. cendriers,) underneath the fire-bars of the furnaces, where the ashes collect. Sp. ceniceros.

Atmospheric or single-acting engine, (Fr. machine à vapeur atmosphérique,) a condensing engine in which the pressure of the steam acts during the up-stroke only, the return stroke being performed by the pressure of the atmosphere acting against a vacuum. Sp. máquina atmosférica.

Auxiliary or feeding engine, (Fr. machine alimentaire,) fitted to supply tubular boilers with feed water when the large engines are not working, and the ordinary feed-pumps are therefore inactive. Sp. máquina alimenticia.

Axle, (Fr. tourillon).

¹ A Glossary of Spanish Terms, alphabetically arranged, with French and English translations, is given at page 20, &c.

Babbit's patent bushes are formed of an alloy of 1 lb. copper, 50 lbs. tin, 5 lbs. regulus of antimony.

Sp. metal de Babbit para coginetes ó centros.

Back-balance of eccentric: this is fixed to the back of the eccentric pulley for the purpose of balancing its weight on the shaft. Sp. contrapeso de la escéntrica.

Back-balance of slide-valves, the weight fixed at the extremity of the valve-lever for balancing the weight of the slides. Sp. contrapeso de las válvulas corredizas.

Back-lash, the term given to the jar which ensues when one portion of the machinery which receives motion from another (but without being always in actual contact) has its velocity so increased from some extraneous cause, that it falls back, with a sudden blow, upon the part from which it ought to derive its motion.

Back-links, the links in a parallel motion which connect the air-pump rod to the beam. Sp. barras de la bomba neumática.

Balance-weight, Sp. contrapeso.

Ball-valve, Sp. válvula esferica.

Ballast, (Fr. sable). Sp. lastre.

Banking-up the fires, raking them to the bridge of the furnace, and then smothering them with cinders and small coal, the draught being at the same time checked. By this means the fires are kept in a state of languid combustion, but are ready to burn up briskly again when steam is wanted at short notice, the red-hot mass being then broken up, raked forward, and the draught re-admitted. Sp. hechar atras los fuegos.

Barometer or vacuum-gauge, (Fr. baromètre,) fitted to the condenser of an engine to show the vacuum. It resembles the common weather-barometer, except that the top of the tube is in communication with the condenser. Sp. barómetro.

Barrel of a pump, (Fr. corps d'une pompe). Sp. caja, cuerpo, ó tubo de una bomba.

Base-plate, see *Sole-plate*. Sp. peana.

Beam or side-lever engines, (Fr. machines à balanciers,) are those in which the motion of the piston is communicated to the crank through rocking beams or levers at the sides. Sp. máquinas de balancin.

Beams of a vessel, (Fr. travers). Sp. baos.

Bear, a small apparatus for punching holes by hand. Sp. perro.

Bearers are the cross-bars in the furnaces, supporting the ends of the fire-bars. Sp. sosten de las parrillas.

Bearing, neck, or journal, of a shaft, (Fr. coussinet d'une arbre,) the part which revolves within the pedestal brasses, and supports the weight or strain. Sp. luchadero ó muñon de un ege, cuello.

Bed, Sp. cama.

Bedding of a boiler, the seat on which it rests. Sp. durmientes de la caldera.

Bevel-wheel, Sp. rueda oblicua.

Bilge injection, Sp. inyeccion de la sentina.

Bilge-pumps, worked by the engine, to clear the water from the bilge of the ship. Sp. bombas de purgar.

Blast-furnace, air-furnace, or reverberatory furnace, Sp. horno de reberbero.

Blast-pipe, Sp. tubo de avivar el fuego.

Blowing off, the process of ejecting the super-salted water from the boiler in order to prevent the deposition of scale or salt. Sp. hechar fuera, purgar.

Blow-off cocks and pipes are those through which the brine is ejected. Sp. tubos de purgar la caldera, llaves de purgar.

Blowing through, (Fr. purger d'air,) the process of clearing the engine of air by blowing steam through the cylinder, valves, and condenser, before starting. Sp. purgar de aire.

- Blow-through valve*, (Fr. soupape à purger d'air,) fitted between the valve casing and the condenser for the temporary passage of the steam used in blowing through. Sp. válvula de purgar de aire.
- Boiler, low-pressure, high-pressure*, (Fr. chaudière à basse pression, à haute pression). Sp. caldera de baja ó alta presión.
- Bolt, bolted*, (Fr. boulon, boulonné). Sp. perno, empernado.
- Bolt head and nut shaping machine*, Sp. máquina de recortar tuercas y cabezas de tornillos.
- Boring bar*, Sp. arbol de barrenar.
- Boring head*, Sp. corona de barrenar.
- Boring machine*, Sp. taladro mecánico.
- Boss*, (Fr. renflement,) a centre or swelling of any kind in which a hole or eye is bored. Sp. henchimiento, refuerzo.
- Box-keys* are the upright keys used for turning the nuts of large bolts, or where the common spanner cannot be applied.
- Bracket pedestal or plummer-block*, the fixed support for the bearing of a shaft in motion, formed so that it can be fixed vertically to the frame of an engine or the side of a beam, &c. Sp. muñonera, chumacera.
- Brass*, (Fr. bronze,) an alloy of copper, tin, and zinc, in different proportions. Tough brass, for engine-work, is formed of 10 lbs. copper, $1\frac{1}{2}$ lb. tin, and $1\frac{1}{2}$ lb. zinc. Brass for heavy bearings, of 1 lb. copper, $2\frac{1}{2}$ oz. tin, $\frac{1}{2}$ oz. zinc. Sp. bronce.
- Breadth of a ship*, Sp. manga de un buque.
- Break or brake*, (Fr. frein). Sp. retranca.
- Break lathe*, Sp. torno cortado.
- Bridge* of a boiler, the barrier of fire-bricks, or iron plates containing water, thrown across the furnace at the extreme end of the fire-bars, to prevent the fuel being carried into the flues, and to quicken the draught by contracting the area. Sp. puente de una caldera.
- Brine-pumps* (Fr. pompes de saumure) are worked by the engines to withdraw the super-salted water from the boilers methodically, instead of by periodical blowing off. Sp. bombas de purgar.
- Bucket*, Sp. balde, cubeta, cangilon de rueda hidraulica.
- Buffer*, Sp. coginete, almohadilla.
- Bulk-heads*, (Fr. cloisons). Sp. mamparos.
- Bush*, a lining of brass, steel, or other metal, fitted in an eye or bearing, either to diminish friction or prevent rapid wear. Sp. dado de una roldana; anillo; centro.
- Bush of the stern-post*, Sp. bocina del codaste por donde pasa el eje del tornillo.
- Callipers* are compasses with round legs, used for taking the diameter or thickness of circular or flat inside work about an engine. *Inside callipers* are used for measuring the internal diameter of a brass or hole of any kind. Sp. compas curbo.
- Cam*, for expansion, is a disc of cast iron, having the periphery cut in an irregular figure, for giving the proper motion to the expansion valve. It is graduated in steps, so as to suit the different degrees of expansion. Sp. tope de la válvula de expansion.
- Canvas*, Sp. lona.
- Cap*, Sp. tapa de chumacera.
- Cap of the piston-rod*, Sp. cabezál de la barra del émbolo.
- Carriage by sea*, (Fr. transportation); *by land* (Fr. montage). Sp. transporte.
- Cast*, (Fr. coulé). Sp. fundido, colado.
- Cast iron*, (Fr. fonte). Sp. hierro colado.

Cataract, a contrivance introduced into marine engines for softening the fall of the expansion valves when these are made upon the Cornish principle. It consists of a little brass cylinder filled with water or oil, and fitted with a solid piston connected by a cross-head with the valve spindle. The fall of the valve is checked and regulated by the escape of the water or oil through a small hole bored for that purpose in the side of the cylinder, the piston of the cataract descending according as the liquid is forced out from before it by the pressure due to the weight of the expansion valve.

Cement, (Fr. ciment, mastice). Sp. cemento.

Centre-boss, of the paddle-wheels, (Fr. renflement central des roues à aubes). Sp. centro de las ruedas de un vapor.

Change wheels, Sp. ruedas de cambio de un torno.

Chimney, (Fr. cheminée). Sp. chimenea.

Chisel, (Fr. ciseau, burin). Sp. cincel, corta hierro.

Chuck, Sp. choque.

Clack-valve, a flat valve with a hinge-joint. Sp. válvula de arandela.

Clearance of the piston is the small space left between the piston and the top and bottom of cylinder at the end of each stroke. Sp. clara ó luz del émbolo.

Clinkers, (Fr. scories,) the incombustible matter left on the fire-bars during the combustion of the coal. Sp. cenizas, escorias.

Clinker-bar, a bar fixed across the top of the ash-pit to support the *slice* used for clearing the interstices of the bars.

Clothing the steam-pipes, boilers, &c., means covering them with felt and other non-conducting materials, to prevent the radiation of heat. Sp. forrar tubos ó calderas.

Coach screws, Sp. tornillos de rosca de madera.

Coals; *coal-bunkers*, (Fr. les houilles, charbon de terre; soutes à charbon). Sp. carbon de piedra; carboneras.

Coal-trimmer, a man whose duty it is to work within the coal-boxes and bring the coals to the doors at the boiler front as they continue to be consumed. Sp. apaleador.

Cock, (Fr. robinet). Sp. llave; grifo.

Cogged wheels (Fr. roues dentées) are those fitted with wooden teeth or *cogs*, for the purpose of lessening friction and giving smoothness of action. Sp. ruedas dentadas con madera.

Cold-chisel, a chisel properly tempered for cutting cold iron. Sp. corta hierro, corta frio.

Collar of a shaft, (Fr. collier,) the projecting rim on each side of the neck or bearing, to confine it sideways during its revolution. Sp. collarin, regola.

Collar-plate, Sp. collar.

Common steam, (in contradistinction to *super-heated* steam,) is steam in contact with the water from which it was generated.

Condenser, (Fr. condenseur,) the cast-iron box in which the process of condensation takes place. Sp. condensador.

Condensing engine, (Fr. machine à condensation,) one in which the steam is condensed after leaving the cylinder, for the purpose of gaining the effect of the atmospheric pressure. Sp. máquina de condensacion.

Connecting rod, (Fr. bielle de la manivelle :) in a direct-acting engine it communicates the motion directly from the head of the piston-rod to the crank; in a side-lever engine, from the cross-tail to the crank. Sp. barra de coneccion.

Connecting-rod strap, Sp. estrobo de la barra de coneccion.

Consumption of fuel, (Fr. consommation de combustible). Sp. consumo de combustible.

Counter, a little instrument employed for registering the strokes of an engine. Sp. soplón.

Coupling of a shaft is the mode of connecting together two or more lengths of a revolving shaft, by shaping the ends into flat surfaces or bearings, which are held together by a strong iron collar or *coupling-box*. Sp. junta de un eje.

Cover or lap of the slide-valve on the steam side, the space which it advances beyond the opening of the steam-port after it has closed it, and given for the purpose of causing the engine to work expansively, by cutting off the admission of steam before the end of the stroke. Sp. avance de una válvula corrediza, en el lado del vapor, ó de la entrada.

Cover or lap on the exhausting side of the piston: this causes the passage to the condenser to be closed before the end of the stroke, the piston being then said to be *cushioned* by the elasticity of the confined vapour upon which it descends. Sp. avance en el lado del vacío, ó de salida.

Crane, Sp. pescante.

Crank; cranked, (Fr. manivelle, coude; coudé). Sp. manubrio, ciqueñal; enciqueñado.

Crank-pin, Sp. perno del ciqueñal.

Crank planing machine, Sp. cepillo de ciqueñal.

Crew of a vessel, (Fr. l'équipage d'un vaisseau). Sp. tripulacion, dotacion.

Cross-head, (Fr. traverse, tête croissée,) in a side-lever engine, crosses the head of the piston-rod, and communicates the motion to the side-rods. Sp. cruceta.

Cross-tail, in a side-lever engine, takes the motion from the side-rods and communicates it to the connecting rod. Sp. cruceta de la barra de coneccion.

Cup-valve, resembling a conical valve, but having no spindle, being turned in the form of a cup or portion of a sphere. Sp. válvulas cónicas.

Cushioning the piston means that a small portion of steam is shut up between the piston and the cylinder top and bottom at the end of each stroke, which acts as a spring to soften the shock, and to give the piston a start forward after the centre is turned. This effect is produced by the lap of the side-valve on the exhausting side.

Cutter, (Fr. clavette,) the wedge-key used, in combination with the *gib*, (Fr. contre-clavette,) for tightening the strap and brasses of a bearing, as the latter wear by friction. Sp. chaveta, cuña.

Cutters, Sp. cuchillas para la corona de barrenar ú otras.

Cutting off the steam for expansion, (Fr. la détente). Sp. cortar el vapor.

Cylinder cover, (Fr. couvercle de cylindre). Sp. tapa ó plato del cilindro.

Dampers (Fr. les registres) are iron plates, fitted by a hinge or otherwise across the fronts of the ash-pits and the bottom of the chimney, for the purpose of regulating the draught. They are capable of being adjusted by hand to any desired area. Sp. registros de la chimenea ó fornalla.

Dead-fires, those which burn sluggishly.

Dead-plate, a flat iron plate frequently fitted before the bars of a furnace, for the purpose of coking bituminous coal upon before it is thrown back upon the fire.

Dead-water, (Fr. eau mort,) the current following in the wake of a ship and partaking of her motion. Sp. estela.

Deck, (Fr. pont). Sp. cubierta.

Depth of a vessel (Fr. hauteur d'un vaisseau). Sp. puntal de un buque.

Depth in the hold, Sp. puntal.

Diagram of indicator, the figure traced by the pencil, from which the pressure is calculated. Sp. muestra del indicador.

Dip of the wheels, the depth of water over the top of the vertical board. Sp. immersion de las paletas.

Direct-acting engines are those in which the motion of a piston is communicated *directly* from the head of the piston-rod to the crank through the connecting rod, without the intervention of side-levers. Sp. máquinas de vapor de accion directa.

Disc-valve, Sp. válvula de disco.

Discharge, delivery, or waste-water pipe and valve, (Fr. tuyau et soupape de décharge, ou de sortie,) those through which the heated condensing water and vapour are discharged into the sea by the air-pump. Sp. tubo y válvula de descarga.

Disengaging or disconnecting the paddles or screw from the engines, (by suitable machinery,) permitting them and their shaft to revolve freely in the brasses by the reaction of the water, by which means the speed of the ship when under canvas is not so much affected as if they were dragged through the water. Sp. desconectar las ruedas ó el tornillo.

Displacement of a vessel, the weight of water which she *displaces*, being of course equal to her own weight. Sp. desplazamiento.

Donkey or auxiliary engine, (Fr. machine alimentaire,) used for feeding the boilers while the large engines are at rest. Sp. máquina alimenticia.

Double-acting engine, (Fr. machine à double action,) one in which the steam acts against a vacuum on each side of the piston alternately, as in the ordinary marine engine. Sp. máquina de doble accion.

Double-acting pump, one which lifts and forces water alternately, by means of a solid piston or plunger and an entrance and exit valve communicating with each side (as the feed and bilge pumps of a marine engine). Sp. bomba de doble accion.

Double-cylinder engine, as patented by Messrs. Maudslay, having two cylinders, between which the lower end of the connecting rod descends, its motion being communicated from the piston-rod by a bent cross-head working in grooves between the cylinders. Sp. máquina de doble cilindro.

Draught of the chimney, (Fr. tirage). Sp. tiro de la chimenea.

Draught of water, (Fr. immersion). Sp. calado.

Drift, a round piece of steel, made slightly tapering, and used for enlarging a hole in a metal plate by being driven through it. Sp. punzon.

Drill, Sp. broca, taladro.

Drill braces, Sp. maniguetas de taladro.

Drilling and boring machine, Sp. máquina de taladrar y barrenar, taladro mecánico.

Drip-pipe, a small copper pipe leading from the waste-steam pipe inside, to carry off the condensed steam and other hot water which may be blown into the 'trap' at the top.

Driving apparatus, Sp. aparato motor.

Driving wheel, (Fr. roue motrice,) in the gearing of a screw vessel, that which communicates motion to the small wheel or *pinion*. Sp. rueda motriz ó motora.

Drum, a hollow cylinder fixed on a shaft for driving another shaft by a band. Sp. tambor.

Duty of an engine, Sp. trabajo medio de una máquina.

Dynamometer, an instrument for indicating the thrust of the screw-propeller by means of springs and levers. Sp. dinamómetro.

Eccentric, (Fr. l'excentrique,) the arrangement usually adopted for giving the proper stroke to the valves. It consists of the *eccentric pulley* of cast iron, which is loose on the intermediate shaft, and the *hoop* of wrought iron lined with brass, which encircles the pulley, and gives motion to the *eccentric rod*. The *eccentric stops* or *snugs* are two little projections fixed on the intermediate shaft for the purpose of carrying round the eccentric pulley, according as it is wanted to go ahead or astern, the pulley itself being free to revolve backwards or forwards between the two

stops. The weight of the pulley is balanced on the shaft by the back-balance cast on it. Sp. *escéntrica*.

Eduction or exhaust passages, (Fr. tuyaux de sortie, ou d'émission,) those through which the steam passes from the valves to the condenser. Sp. *portas ó tubos de salida*.

Effective diameter of a paddle-wheel is generally reckoned at one-third of the breadth of the boards from each extremity of the diameter. Sp. *diametro de las ruedas de un vapor*.

Effective heating surface in a boiler is that which is considered of value in evaporating the water. The bottom surface of the flues and furnaces, and one-third of the whole surface of the tubes in tubular boilers, are usually rejected as *ineffective*. Sp. *superficie de calórico ó de fuego*.

Elbows, Sp. *codillos*.

Engine beams cross through the engine-room at the height of the entablatures, to steady them, and to receive part of the thrust of the paddle-wheels. Sp. *baos de la máquina*.

Engine bearers or sleepers, (Fr. poutres de fondement,) the longitudinal keelsons through which the foundation plate is bolted. Sp. *durmientes de la máquina*.

Engineer, engine tender, (Fr. machiniste, mecanicien). Sp. *máquinista*.

Entablature, the strong iron frame supporting the paddle-shaft. It usually receives additional stiffness from being confined between two beams of timber, called the *entablature* or *engine beams*. Sp. *entabladura*.

Equilibrium, Cornish, or double-beat valves, are frequently used in marine engines as expansion valves. Their peculiarity consists in their being pressed by the steam equally in all directions, so that they rise with a very slight force, exposing at the same time a large area of steam with a very small rise of the valve. Sp. *válvulas dobles ó de equilibrio*.

Escape or priming valves (Fr. soupapes d'échappement) are loaded valves fitted to the top and bottom of the cylinder, for the escape of the condensed steam, or of water carried mechanically from the boilers with the steam. Sp. *válvulas de escape del cilindro*.

Escape-valves are also fitted to the feed-pipes as a means of exit for the surplus water not used by the boilers. Sp. *válvulas de escape de la bomba alimenticia*.

Expansion gear (Fr. l'encliquetage pour l'expansion) is fitted to marine engines, independently of the cylinder valves, for the purpose of cutting off the steam at different portions of the stroke, according as it is wished to economize fuel more or less. It generally consists of a graduated *cam* on the paddle-shaft, against which a *roller* presses and communicates the movement peculiar to the irregular surface of the cam, through a series of rods and levers to the *expansion valve*, situated between the throttle-valve and the slides. Sp. *aparato de la expansion*.

Expansion or Fawcett joint, a stuffing-box joint used when a straight metal pipe, (as the steam-pipe,) which is exposed to considerable variations of temperature, has no *elbow* or curve in its length to enable it to expand without injury. In such a case the pipe is divided into two lengths, which are united by a steam-tight joint accurately bored and turned, so as to allow the one pipe to slip within the other, when they lengthen by expansion. Sp. *junta de expansion*.

Experiment, (Fr. expérience). Sp. *experimento*.

Eye of a crank, &c. (Fr. encoche, œil,) a hole bored to receive a shaft or pin. Sp. *ojo de un ciqueñal*.

Fan, Sp. *abanico*.

Fawcett joint, see *Expansion joint*.

Feathering paddle-wheels (as Morgan's patent) are those which have the requisite machinery for *feathering the boards*, or causing them to enter and leave the water in a perpendicular position. By this means

- the board leaves the water without lifting it, and the effect of the wheel is somewhat increased.
 Sp. ruedas de Morgan, ó de paletas movibles.
- Feeding apparatus*, (Fr. l'appareil alimentaire, Sp. aparato alimenticio,) for a marine boiler, consists of the *feed-pump* (Sp. bomba alimenticia), *feed-pipe* (Sp. tubo alimenticio), passing through the *refrigerator* (Sp. refrigerante), *feed-cock* (Sp. llave alimenticia) on the boiler, *escape-valve* (Sp. válvula de escape) for the surplus water, and *water-gauges* to show the level in the boiler (Sp. llaves de prueba para medir el agua de la caldera).
- Feeding engine*, see *Auxiliary engine*.
- Felting*, Sp. forrar de fieltro.
- Ferrules* (Fr. viroles) are rings of iron or brass frequently used for fastening the tubes of a tubular boiler in the tube-plate. Sp. virolas.
- Files*, (Fr. limes). Sp. limas.
- Fire-bars*, (Fr. barres du foyer). Sp. parrillas.
- Fire-box*, Sp. fornalla, horno.
- Fire-engine*, Sp. bomba de incendios.
- Fire-grate*, (Fr. grille du foyer). Sp. emparrillado.
- Fire-hose*, that which is made adjustable to the discharge-pipes from the bilge-pumps, from the auxiliary engine where fitted, and from the hand-pump in engine-room. Sp. manquera.
- Fire-men or stokers*, (Fr. chauffeurs,) the men who work the fires. Sp. fogoneros.
- Firing-up*, urging the fires to make them form as much steam as possible. Sp. atizar.
- Flange*, (Fr. rebord). Sp. orilla, franja, regola.
- Flange of a wheel*, Sp. franja ó yanta de una rueda.
- Float-boards or paddle-boards*, (Fr. les aubes). Sp. paletas.
- Flues*, (Fr. conduits). Sp. fluses.
- Fly-wheel*, Sp. volante, rueda voladora.
- Foot-valve*, (Fr. clapet de fond,) the valve situated between the bottom of the condenser and the air-pump, opening towards the latter. Sp. válvula de pie.
- Forcing pumps*, (Fr. pompes foulantes). Sp. bomba de fuerza ó de impulsion.
- Fork*, (Fr. fourche). Sp. horquilla.
- Fork-head*, the double head of a rod which divides in order to form a connection by means of a pin. Sp. remate horquillado.
- Foundation or base plate*, (Fr. plaque du fond,) see *Sole-plate*. Sp. peana.
- Fox key*, a key with a thin wedge of steel driven into the end to prevent its working back.
- Frame of the engine*, (Fr. châssis, cadre). Sp. armazon.
- Frames of a vessel*, (Fr. membrures d'un vaisseau). Sp. miembros.
- Friction*, (Fr. frottement). Sp. fricción, roce.
- Fuel*, (Fr. combustible). Sp. combustible.
- Fulcrum*, (Fr. support, palier, crapaudine). Sp. punto de apoyo.
- Furnace*, (Fr. le foyer). Sp. fornalla, horno.
- Fusible Plugs* (Fr. bondelles fusibles) are sometimes fitted in boilers, being expected to melt by the high temperature of the confined steam, and thus allow it to escape in case of its attaining a dangerous pressure from the safety-valve not acting. Sp. tapon fundible.
- Gasket*, (Fr. garniture d'étoupe,) the hemp packing, formed of soft cord plaited, which is used for making steam-tight joints. Sp. cageta para empaquetar.
- Gauges*, Sp. vitolas.

Gauge-cocks, (Fr. robinets d'épreuve,) of brass, attached to the front of the boiler for indicating the level of the water. Sp. llaves de prueba.

Gauge, steam or mercurial, (Fr. manomètre de verre mercurial,) a syphon tube half-filled with mercury, usually employed for showing the pressure of low steam. When a marine boiler uses steam of high tension, a spiral spring is employed. Sp. manómetro.

Gearing, Sp. aparato, maquinaria.

Gib (Fr. contre-clavette), the fixed iron wedge used, in conjunction with the *cutter* or driving-wedge (clavette), for tightening the straps and brasses of the different bearings. Sp. perro, cepo.

Gland, the cupped collar (lined with brass) which encircles the piston and air-pump rod, &c. where it passes through the cover, being for the purpose of holding oil or tallow for lubricating, and for compressing the packing of the stuffing-box, upon which it is screwed down. Sp. collarin de la barra del émbolo.

Glass water-gauges, those attached to the fronts of the boilers for showing the level of the water. Sp. hidrómetros.

Governor, (Fr. régulateur,) in screw engines, an apparatus by which the steam is shut off from the cylinders (when the speed of the engine becomes too great), by the divergence of two balls from the centrifugal force, according as their velocity is increased. Sp. regulador.

Grease-cock, that on the cylinder cover, for lubricating the piston with melted tallow, without permitting the escape of steam or the entrance of air. Sp. copas de lubricar.

Groove, (Fr. trou, entaille). Sp. ranura.

Guards for the bolts of an engine are light frames of brass or iron, into which the nuts of the bolts fit, to prevent their working loose by unscrewing. Sp. guardas de tuercas.

Gudgeon, (Fr. goujon,) any short pin or shaft used as a bearing for a moving portion of the machinery. Sp. pernete, muñon.

Guide-screw, Sp. tornillo alimenticio, ó de guia.

Guide-screw stock, Sp. tarraja de mano de Whitworth.

Guides, (Fr. glissiers,) smooth surfaces between which the head of a piston-rod, &c. slides to preserve its parallelism; the sliding block attached to the cross-head being called the *Guide-block*. Sp. guias.

Gun-metal, an alloy of brass very generally employed in engine-work. It is formed by melting together 1 lb. of tin, 1 lb. zinc, and 8 lbs. copper. Sp. bronce.

Hall's condenser, a method of surface condensation in which the steam is condensed by passing through a large number of small tubes immersed in cold water.

Hammers, (Fr. marteaux,) of three sizes, the largest being called *sledge hammer*; the next *flogging hammer*; and the smallest *hand hammer*. Sp. martillos.

Handle, (Fr. manette). Sp. mango.

Hand-pump, (Fr. pompe à bras,) a pump fitted in the engine-room for filling and feeding the boilers by hand, for washing the decks, extinguishing fire, &c. It is always made capable of being attached to the engines when they are working. Sp. bomba de mano.

Hand-rail, Sp. pasamano.

Head of water, Sp. columna vertical de agua.

Head stock, Sp. cabezál de un torno.

Heat, Sp. calor.

Heat, heating power, (Fr. chaleur, puissance calorifique). Sp. calor, fuerza calorifica.

Helm, helmsman, (Fr. timon, timonier). Sp. timon.

Hemp, (Fr. étoupe). Sp. estopa.

High-pressure, or more correctly *non-condensing engines*, (Fr. machines à haute pression,) are those which work simply by the excess of the pressure of the steam above that of the atmosphere. Condensing engines, although sometimes using 'high-pressure' steam, are never called high-pressure engines. Sp. máquinas de alta presión.

High-pressure steam, (Fr. vapeur à haute pression,) a vague expression denoting steam of a tension above 15 or 20 lbs. pressure above the atmosphere. Sp. vapor de alta presión.

Hinges, Sp. gonces, visagras.

Holding-down bolts are the strong screw-bolts employed to fasten the foundation plate of the engines to the ship's bottom. Sp. pernos de asegurar la máquina.

Horse-power, nominal, (Fr. puissance en chevaux, force de cheval,) is assumed equal to 33,000 lbs. raised one foot high in one minute. Sp. caballo de vapor.

Hot-well, (Fr. réservoir à l'eau chaude, la citerne,) the reservoir for the water pumped out of the condenser by the air-pump. Sp. depósito de agua caliente.

Hugging is the expression used when one vessel is running so close in the wake of another as to be influenced by the current of dead-water following her, in which case the two may continue to keep close together, although the vessel running behind may be, perhaps, a mile an hour slower than the other.

Hull or shell of a boat, (Fr. coque d'un bateau). Sp. casco de un buque.

Hydraulic ram, Sp. ariete hidráulico.

Incrustation or scale, (Fr. sédiment,) the hard coating of salt, lime, and other mineral substances which collect on the inner surface of the plates of a boiler which is not regularly and sufficiently 'blown off.' Sp. incrustación, sedimento.

Index of a spring balance, (Fr. curseur).

Indicator, (Fr. indicateur,) the little instrument employed for ascertaining the real power, as well as the state of efficiency of the internal parts, of a steam engine, by indicating the actual pressure in the cylinder during each stroke, and the time and manner in which the steam is admitted and shut out by the valves. Sp. indicador.

Injection, (Fr. injection,) the process of admitting a jet of cold water from the sea into the condenser, to condense the steam as rapidly as possible. Sp. inyección.

Inside bearings of paddle-shaft (upon a bracket bolted to the ship's side) are employed when the wheels are 'overhung.' Sp. chumacera del costado.

Intermediate shaft, the strong shaft crossing the centre line of the vessel and connecting the paddle-shafts of the two engines. Sp. eje intermedio.

Iron filings, (Fr. limaille). Sp. limaduras de hierro.

Joints, (Fr. charnières, articulations). Sp. juntas.

Journal, (Fr. coussinet,) the neck or bearing part of a shaft, upon which it turns and by which it is supported. Sp. luchadero, cuello de un eje.

Junk ring, a metallic ring confining the hemp packing of the piston (when such is employed), and made capable of being screwed down to compress it. Sp. anillo del empaquetado de un émbolo.

Keel, Sp. quilla.

Keelsons, (Fr. carlingues). Sp. sobre quillas.

Key, (Fr. clef,) a wedge-piece of iron used for tightening the brasses of a bearing, &c. Sp. cuñas, chavetas.

Kingston's valves are conical valves with a screwed spindle, and are very generally used for closing the orifices of the injection and blow-off pipes where they pass through the ship's side. Sp. válvulas con el ege enroscado.

Knees of iron, (Fr. équerres en fer). Sp. curvas de hierro.

Laggings for the cylinder, &c., are the thin staves of wood employed in 'clothing,' to stop the radiation of heat and consequent condensation of steam. Sp. forro del cilindro.

Lap of the slide-valve, see *Cover*.

Larboard engine, that on the left-hand side of the vessel when looking towards the bow. Sp. máquina de babor.

Latent heat (Fr. chaleur latente) is that portion of heat which is absorbed by gases and liquids, in a latent or insensible state, during their transition from a denser to a rarer form; as when water at 212° changes into steam at 212° , and when ice at 32° changes into water at 32° . Sp. calor latente.

Lathe, Sp. torno.

Lead of the slide-valve, (Fr. avance du tiroir,) the small space which the valve opens to steam at the end of each stroke, upon the opposite side of the piston. It tends to check the velocity of the piston at the end of the stroke, and allows of the valve being open and ready to admit a larger supply of steam the instant the motion of the piston is reversed. Sp. avance de la válvula corrediza.

Lead of the crank, (Fr. avance de la manivelle). It is usual in direct-acting, and generally in all unbalanced engines, to give what is called *lead* to one of the cranks; which implies that the crank of the one engine is set a little in advance of the right angle to the other; namely, at 100° or 110° in place of 90° . This assists in rendering the motion of the piston more uniform, by moderating its velocity at the end of the stroke. Sp. avance del ciqueñal.

Leak, Sp. hacer agua, salirse el agua ó el vapor.

Leather, (Fr. cuir). Sp. cuero.

Lee-way, Sp. abatimiento de un buque.

Length of a ship, Sp. eslora de un buque.

Length of stroke, (Fr. longueur du coup, ou de la course). Sp. longitud del golpe.

Level, (Fr. niveau). Sp. nivel.

Lever, (Fr. levier). Sp. palanca.

Lever of a valve, Sp. romana de una válvula.

Lighter or barge, (Fr. gabarre). Sp. lanchon, gavarra.

Links are short connecting pieces, with a bearing in each end, for transmitting motion from one rod or lever to another. Sp. palanquillas.

Link motion, or quadrant motion, is an ingenious arrangement for working the slides, by which means the travel or stroke of the valve may be varied at pleasure, and expansion given without a separate expansion valve being required. It also affords great facilities for stopping and reversing the engines. Sp. cuadrante de las válvulas corredizas.

Linseed oil, Sp. aceite de linaza.

Log, engine-room, a tabulated summary of the performance of the engines and boilers, and of the consumption of coals, tallow, oil, and other engineers' stores. Sp. diario de máquina.

Lubricators (Fr. godets, ou boîtes à huile) are the larger description of oil-cups for holding oil and distributing it to the working parts of the engines. Sp. lubricadores.

Machinery, Sp. maquinaria.

Main centre, (Fr. goujon central,) in side-lever engines, is the strong shaft upon which the side levers vibrate. Sp. centro de los balancines.

Man-hole, (Fr. trou d'homme,) a hole in a boiler or tank, fitted with a steam-tight cover, through which a man may enter for the purpose of cleaning and examining the interior. Sp. boca ó puerta de la caldera.

Master-tap, Sp. macho de tarrajar y concluir las tuercas.

Metallic packing (for the piston) is composed of a ring or several rings of iron or other metal, sometimes cast so as to possess elasticity in themselves, or sometimes cut into segments and pressed against the interior of the cylinder by springs, so as to form a steam-tight contact. Sp. empaquetado metálico.

Metre, equals 39·3702 English inches. Sp. metro.

Mile, Geographical or Nautical, or *knot*, contains 6082·66 feet. Sp. milla nautica, nudo.

Mile, British Statute, contains 5280 feet, 1760 yards, or 1609 metres.

Mile-post, (Fr. borne milliaire).

Mitre-wheel: the teeth are set at an angle of 45° with the spindle, so as to transmit the motion to another mitre-wheel and shaft at right angles with it. Sp. rueda en angulo de 45°.

Morgan's feathering paddle-wheel, see *Feathering paddle-wheels*. Sp. rueda de Morgan.

Mortise, Sp. escopleadura, ranura, cagera.

Mortised, (Fr. assemblé à mortaise). Sp. escopleado.

Mud-hole, (Fr. orifice de nettoyage,) a space fitted with steam and water tight doors, through which the deposit may be removed from the boilers. Sp. registro de limpieza en las calderas.

Muntz's metal, used for bearings, &c., is formed of two parts of zinc, three parts copper. Sp. metal de Muntz.

Nave of a wheel, (Fr. moyen). Sp. centro.

Neck of a shaft, (Fr. coussinet d'un arbre,) the *journal* or *bearing* on which it turns and is supported. Sp. cuello de un eje.

Non-condensing or high-pressure engines (Fr. machines à haute pression) are those in which the principle of condensation is not applied, the motive power being due solely to the excess of the pressure of the steam above that of the atmosphere. Sp. máquinas de alta presión.

Notch, (Fr. encoche). Sp. mortaja.

Nut, (Fr. écrou). Sp. tuerca.

Oil-cups or lubricators (Fr. boîtes à huile) are fitted to the several bearings and rubbing surfaces of the engine, for the purpose of lubricating them to diminish friction. Sp. lubricadores.

Oscillating engines (Fr. machines aux cylindres oscillantes) are those in which the cylinders oscillate upon hollow axes or *trunnions*, through which the steam enters the valve-casing. By this

arrangement the parallel motion and connecting rod are dispensed with, the head of the piston-rod being attached directly to the crank-pin. Sp. máquinas oscilatorias.

Outside bearings to paddle-shaft, so called when the shaft runs through to a bearing on the spring beams. Sp. chumaceras de afuera.

Overhung paddle-wheels, so called when the shaft does not run through to a bearing on the spring beams, but is supported by a bracket from the ship's side.

Packing for the piston, slide-valves, &c., (Fr. garniture,) is employed to render them steam-tight, and is formed sometimes of rings of iron or other metal pressed outwards by springs (when it is called metallic packing); sometimes by hemp confined by a 'junk ring' and compressed by screws (called hemp packing); and sometimes by rings of vulcanized India rubber and other elastic material. Sp. empaquetado del émbolo, &c.

Paddle-wheels, paddle-boxes, (Fr. roues à aubes, tambours). Sp. rueda de un vapor, tambores.

Paddle-boards or float-boards, (Fr. les aubes); *paddle-arms*, (Fr. les rais des roues). Sp. paletas.

Parallel motion (Fr. le parallélogram) is the name given to the combination of jointed rods usually employed in side-lever engines (and others) for preserving the parallelism of the piston-rod. Sp. movimiento paralelógramo.

Pedestal or plummer block is the support for a shaft in motion, holding the brasses on which it turns. Sp. chumacera ó pedestal del eje.

Pet cock or test cock is the name given to a little cock sometimes fitted at the top and bottom of the cylinder to allow the escape of water from above and below the piston, independently of the escape-valves fitted for that purpose. They are kept open until the engines are fairly under weigh, and are then shut. Sp. llave de hechar fuera el agua del cilindro.

Pin, (Fr. happe, boulon). Sp. pernete.

Pinion, Sp. piñon.

Pipe, Sp. tubo.

Pitch of a screw is the distance between the threads, or the distance which the screw advances during each revolution when working in a solid. Sp. avance de un tornillo.

Pitch of a wheel, Sp. abra de dientes, distancia de centro á centro de dientes medida en el círculo primitivo ó de contacto de una rueda.

Pitch circles are the circles of contact of two or more toothed wheels working in combination. Sp. círculo primitivo ó de contacto de una rueda dentada.

Pitching of a vessel, (Fr. plongement). Sp. cabezada de un buque.

Planing machine, Sp. máquina de cepillar, cepillo mecánico.

Plank, Sp. tablon.

Plate-bending machine, Sp. máquina de doblar planchas.

Plates, (thin,) (Fr. lames, tolles). Sp. planchas de hierro, &c.

Plug, (Fr. bouchon). Sp. tapon, tarugo.

Plummer-block, see *Pedestal*.

Plunger, (Fr. plongeur,) a solid piston without valves, used in the feed and bilge pumps, &c. Sp. émbolo sin válvulas de una bomba.

Ports of the cylinder are the short steam passages leading from the top and bottom of the cylinder to the slide-valve casing. Sp. portas del cilindro.

Priming or foaming of the boilers implies that the water boils over into the steam-pipes which lead

to the engines, and is caused by the water being dirty, or there being a deficiency of steam room in the top of the boilers. Sp. fomentar las calderas.

Priming valves, see *Escape-valves*.

Pulley, Sp. polea.

Pump-ram, Sp. ariete de una bomba, émbolo cilindrico que batalla en el empaquetado de la regala de una bomba de fuerza.

Punching and shearing machine, Sp. punzon y tigera mecánicos.

Putty, Sp. macilla.

Radius of curvature, (Fr. rayon de courbe). Sp. radio de una curva.

Radius rods or bars (Fr. la bride du parallelogram) are the guiding rods in a parallel motion jointed to the connecting links, to counteract the vibratory motion communicated by the side levers. Sp. radios del paralelógramo.

Ratchet-wheel, Sp. rueda de linguete.

Reciprocating, (Fr. alternatif). Sp. movimiento alternado.

Red-lead, Sp. minio.

Reefing the paddles means disconnecting the float-boards from the paddle-arms, and bolting them again nearer the centre of the wheel, in order to diminish the dip when the vessel is deep. This is sometimes done by machinery in what are called *reefing paddle-wheels*. Sp. arrizar las paletas.

Refrigerator, a vessel containing a number of copper tubes through which the hot brine passes after being ejected from the boiler by the brine-pump. The feed water is at the same time passed through the vessel surrounding the tubes, and has its temperature thus raised by the waste heat of the brine before entering the boiler. Sp. refrigerante.

Reverberatory furnace, Sp. horno de reberbero.

Reverse or vacuum valves (Fr. soupapes de sûreté intérieures) are small loaded valves opening inwards, and fitted to the boiler to admit air when a vacuum is formed by the condensation of the steam inside, or when the pressure of the steam falls to a few pounds below the pressure of the atmosphere. Sp. válvulas atmosféricas.

Reversing gear is the apparatus provided for reversing the motion of the engine by changing the time of action of the slide-valve. This is done by bringing the eccentric *behind* in place of *in advance* of the crank. Sp. aparato para hechar para atras la máquina.

Ribs, (Fr. tirans). Sp. ligazones.

Rivet, Sp. remache, redoblon.

Riveting machine, Sp. máquina de remachar.

Rocking shaft, the shaft, with levers, frequently used for working the slide-valves, the notch of the eccentric rod dropping into a stud fixed in one of the levers, and the links of the slide-valve spindle being attached to the opposite lever on the same shaft.

Rubbing part, (Fr. partie frottante). Sp. parte que roza.

Rudder, (Fr. gouvernail). Sp. timon.

Rust joints are made by spreading over the surfaces to be united a mixture of one ounce of sal-ammoniac to one pound of cast-iron borings. Sp. juntas de cemento.

Safety-valves, (Fr. soupapes de sûreté,) those fitted to the boilers for the escape of the steam before it attains a dangerous pressure. Sp. válvulas de seguridad.

Salinometer, (Fr. salinomètre,) an instrument for measuring the quantity of salt contained in solution

in the water of the boiler, by indicating either the specific gravity, or the temperature at which it boils. Sp. salinómetro.

Scale (Fr. sédiment) is the hard crust of salt, lime, &c., which collects upon the interior surface of the plates of a boiler when proper attention is not paid to 'blowing off.' The hammers used for loosening and removing the scale are called *scaling hammers*. Sp. depósito, sedimento.

Screw, screwed, (Fr. vis, vissé). Sp. tornillo; tornillado.

Screw-bolts, (Fr. boulons en vis, boulons taraudés). Sp. tornillos; pernos de tornillo.

Screw Tack, Sp. gato.

Screwing machine, Sp. máquina de tarrajar.

Seat of the valve, (Fr. siège de la soupape). Sp. asiento de una válvula.

Sediment collectors or *scale-pans* are shallow vessels which are sometimes fixed in boilers about the level of the water, for collecting the particles of sediment which are buoyed up to the surface by bubbles of steam, and which would otherwise settle at the bottom of the boiler.

Self-acting lathe, Sp. torno mecánico de alimento propio.

Sensible heat (in opposition to *latent heat*) is free caloric, which is sensible to, or whose presence is indicated by, the thermometer. Sp. calor sensible.

Shaft, (Fr. arbre). Sp. ege.

Shaping machine, Sp. máquina de recortar, recortador.

Shears, Sp. machina, cabria, tigas.

Sheet iron, (Fr. tôle, fer en feuilles). Sp. chapa de hierro.

Shelf, Sp. cairel.

Shell of a boiler, Sp. casco de una caldera.

Shovel, (Fr. pelle). Sp. pala.

Shrouds for the funnel are the supporting chains from the deck. Sp. vientos de la chimenea.

Side-levers, in side-lever engines, (Fr. balanciers,) transmit the motion of the piston-rod from the side-rods to the cross-tail of the connecting rod. Sp. balancines.

Sleepers or *engine bearers*, (Fr. traverses). Sp. durmientes de la máquina.

Slice, (Fr. fourgon, tisonnier,) the instrument used for clearing the air spaces between the bars of a furnace when they become choked with *clinkers*. Sp. atizador, sable.

Slide-casing or *jacket*, (Fr. boîte des tiroirs,) the cast-iron box within which the slide-valves work. Sp. caja de las válvulas corredizas.

Slide-rest, Sp. soporte mecánico ó corredizo.

Slide-valve travel, Sp. viaje de la válvula corrediza.

Slide-valves (Fr. tiroirs, soupapes à tiroir) are much used for the cylinder steam-valves of marine engines.

The two kinds most commonly found are called 'long D' and 'short D' valves, from the form of their cross section; the distinction being that in the first case the steam enters round the outside of the valve, and exhausts through it, while, in the second, the exhaust takes place alternately from the top and bottom of each of the two short slides, which are strongly joined together by vertical rods. Sp. válvulas resbaladizas ó corredizas.

Slip, Sp. pérdida.

Slip of the paddle-wheel or *screw*, the amount which each *slips back* in its progress through the water in consequence of the imperfect resistance offered by the fluid, and therefore equal to the difference between the rate of the wheel or screw and that of the vessel. Sp. pérdida de las paletas ó del tornillo.

Slotting machine, Sp. máquina de escoplear, escoplo mecánico.

Smith (Fr. forgeron). Sp. herrero.

Smoke-box, (Fr. boîte à fumée,) the space in a tubular boiler between the ends of the tubes and the front or back of the boiler. It is fitted with doors which remove for the purpose of cleaning the tubes with *tube-brushes*, and removing ashes and soot. Sp. caja de humo.

Smoke-burning apparatus is sometimes fitted to boilers with the view of effecting a more perfect combustion of the inflammable gases by introducing fresh atmospheric air behind the 'bridge.' Sp. aparato para consumir el humo.

Snap, a tool used by boiler-makers for giving the head of the rivet a round and symmetrical form before it cools, but after it has been *closed*. Sp. estampa.

Snifting valve, (Fr. soupape reniflante,) the small valve fitted to the condenser, and opening outwards for the escape of the air and steam ejected during the process of 'blowing through.' Sp. válvula de purgar de agua el condensador.

Socket, (Fr. socle, crapandine). Sp. soquete.

Solders are alloys of a medium degree of fusibility employed for joining metals together. 'Hard solder' for brass is formed of 3 parts copper, 1 part zinc; soft solder for brass, of 6 parts brass, 1 part tin, 1 part zinc. A common solder for iron, copper, or brass, consists of nearly equal parts of copper and zinc. Sp. soldadura.

Sole plate, *base plate*, or *foundation plate*, (Fr. plaque du fond,) the strong plate which is bolted on the engine bearers, and forms the foundation for the engine. Sp. peana.

Spanners are the keys used for screwing up nuts. Sp. destornilladores; llaves de destornillar.

Spare gear (Fr. pièces de réchange) are carried in Government and other steamers to replace any portions of the machinery which may be broken or injured at sea. Sp. piezas de respeto.

Speed, (Fr. vitesse). Sp. velocidad.

Spindle, (Fr. axe, verge). Sp. ege, pinzote, espiga.

Split pins are those which have a thin wedge of steel inserted in the end to prevent their falling out. Sp. chavetas abiertas.

Springs, (Fr. ressorts). Sp. muelles.

Spring balance, (Fr. balance à ressort,) a spiral-spring weighing balance fitted with steam-tight piston, index plate, and pointer, for showing the pressure of high steam. Sp. peso de muelle.

Spring beams are wooden beams stretched between the ends of paddle-beams to support the bracket for the outside bearings of paddle-shaft. Sp. malletes de la rueda.

Spur-wheel. Sp. rueda dentada ordinaria.

Square, *square foot*, (Fr. quarré, pied carré). Sp. cuadrado, pié cuadrado.

Square tuck, the flat surface left at the stern of a vessel when the planks of the bottom are not worked round to the wing transom, but end in the fashion-piece.

Stand. Sp. peana, sosten, armazon.

Standard. Sp. norma, medida.

Starboard engine, that on the right-hand side of the vessel when looking towards the bow. Sp. máquina de estribor.

Starting gear, (Fr. encliquetage régulateur,) for starting the engines, comprises a wheel for working the slide-valves by hand, and at the same time bringing the eccentric into gear, so as to continue the motion of the valves; a handle to open the throttle-valve, and admit the steam, one to open the 'blow-through valve,' and another to admit condensing water through the injection-cock. Sp. palanca ó rueda de hechar á andar la máquina.

Stays, Sp. sribos interiores de la caldera, tirantes.

Stay wedges, Sp. cuñas ó pernetes de los estribos.

Steam engine, *steam boat*, (Fr. machine à vapeur; bateau á vapeur, pyroscaph). Sp. máquina de vapor, buque de vapor.

Steam-chest, (Fr. réservoir pour la vapeur,) the reservoir for steam above the water of the boiler. Sp. caja de vapor.

Steam room, (Fr. espace pour la vapeur,) the capacity for steam over the surface of the water in the boiler. Sp. depósito de vapor.

Steam-gauge, mercurial, (Fr. manomètre pour la vapeur,) the gauge employed to show the pressure of steam in the boiler by marking the height to which it will raise a column of mercury in a syphon tube. Sp. manómetro.

Steam-tight, (Fr. étanche de vapeur). Sp. á prueba de vapor.

Steam tug, (Fr. pyroscaph remorquant). Sp. remolcador.

Steel, (Fr. acier). Sp. acero.

Steersman, (Fr. timonier). Sp. timonel.

Stern, (Fr. poupe). Sp. popa.

Still or dead water, (Fr. eau morte). Sp. aguas muertas.

Stop valves, or communication valves, are fitted in the steam-pipes where they leave the several boilers, and in the connecting pipes between the boilers, in such a manner that any boiler or boilers may be shut off from the others and from the engines. Sp. válvulas de comunicacion.

Stops or snugs of eccentric are the catches on the eccentric pulley and intermediate shaft, for the purpose of communicating the motion of the shaft, through the eccentric, to the slide-valves, either for going ahead or astern. Sp. topes de la escéntrica.

Stow goods, to, (Fr. charger des marchandises). Sp. estivar.

Straight line, (Fr. ligne droite). Sp. linea recta.

Strain, (Fr. effort). Sp. estrepada.

Strap, Sp. correa, estrobo de una barra.

Stroke of the piston, (Fr. course du piston). Sp. golpe del émbolo.

Stroke of a pump, Sp. golpe ó batalla de una bomba.

Stuffing-box, (Fr. boîte à étouffe, le collet,) the mechanical arrangement by which a rod passes steam-tight through the cover of a cylinder or air-pump, &c. This is effected by the rod being surrounded at that place by a packing of hemp or gasket, which is compressed by means of the collar (with its *brass*) being screwed tight down upon it. The stuffing-box is lubricated with oil or melted tallow, which is poured into the cupped collar surrounding the rod. Sp. caja de empaquetado.

Sucking pump, (Fr. pompe aspirante,) one which raises water by exhausting the air from the barrel of the pump, and into which the water is forced by the external pressure of the atmosphere.

Sp. bomba aspirante.

Suction pipes, (Fr. tuyaux à succion, suçoirs). Sp. chupadores.

Super-heated steam, steam whose temperature has been raised after it has left the water from which it was generated.

Supplementary engine, see *Auxiliary engine*.

Surcharged steam, steam which has an excess of watery particles held in mechanical suspension.

Syphon oil-cups are those fitted with a wick of cotton or worsted hanging over the edge of a little tube in the middle of the cup, the oil rising in the wick by capillary attraction, and dropping down the tube on to the bearing. Sp. lubricadores de sifon.

Table, Sp. mesa de una herramienta mecánica.

Tallow, oil, (Fr. suif, huile). Sp. sebo, aceite.

Tap-wrenches, Sp. garrote de tarrajar.

Taper, Sp. disminucion de mayor á menor.

Taps and *dies* are employed for forming the threads of internal and external screws. The tap is a hard steel screw, grooved from end to end, so as to present a cutting section, and slightly tapered. This is turned round, by hand, inside the nut by means of the *tap-wrench*. Dies are screwed nuts of hard steel, grooved in the same way, for cutting the threads of bolts. Sp. machos y dados (hembras) de tarrajar.

Telescope funnel, Sp. chimenea de anteojo.

Template, (of a base plate, for instance,) is a model or gauge of it in thin sheet iron or wood, having the bolt-holes cut out, and the various centres marked, for the purpose of transferring them to the hull of the vessel. Sp. plantilla.

Test cocks, see *Pet cocks*.

Thread, Sp. tuerca, hilo, gusanillo.

Thread of a screw, (Fr. filet d'une vis). Sp. gusanillo, rosca.

Throttle-valve, (Fr. soupape regulateur,) the valve situated in the steam-pipe close to the slide-valve casing, and used for regulating the flow of steam, which in the marine engine is done by hand. Sp. válvula de paso.

Thrust, Sp. empuge.

Thrust of the screw, Sp. empuge del tornillo.

Tire of the wheels, Sp. la yanta de las ruedas de los locomotores.

Ton equals 2240 lbs.; the French *tonne* equals 1000 kilogrammes, or 2204·86 lbs. avoirdupois. Sp. tonelada.

Tooth, Sp. diente.

Travel of the valves (Fr. course du tiroir) is synonymous with their *stroke*. Sp. viage de las válvulas.

Trunk-engine, one in which the end of the connecting rod is attached to the bottom of a hollow *trunk* fitted to the upper side of the piston, and alternating with it through the interior of the steam cylinder. The trunk itself passes steam-tight through the cylinder cover, by means of a stuffing-box. Sp. máquina de maleta.

Trunnions, of oscillating cylinders, are the hollow axes upon which they vibrate, and through which the steam passes into the belt which leads round the exterior of the cylinder to the valve-casing. Sp. muñones.

Tube-plugs, formed of hard wood, are used for driving into the two ends of a tube that has been burst by the pressure of the steam, as a temporary remedy until a new tube can be put in. Sp. taponos de tubos.

Tubular boilers are those in which the flame and hot gases, after leaving the furnaces, pass through a great number of small iron or brass tubes surrounded with water. Sp. calderas tubulares.

Tug, or *towing boat*, (Fr. remorqueur). Sp. remolcador.

Two-way cock, (Fr. robinet à deux eaux). Sp. grifo ó llave de dos vias.

Up-take is the name given to the flue of a boiler into which the others are gathered at the end of their course, and thus *taken up* into the foot of the chimney. Sp. flus de reunion.

Vacuum-gauge, or barometer, fitted to the condenser to show the vacuum. Sp. barómetro.

Vacuum-pump (the) sometimes fitted to the boilers for the purpose of filling them above the level of the sea, by withdrawing the air from the inside of the boiler, when the water will of course rise by the atmospheric pressure outside.

Vacuum-valves, see *Reverse valves*.

Valves, (Fr. valvules, soupapes, clapets, tiroirs). Sp. válvulas.

Valve-casing, (Fr. boîte du tiroir, boîte à vapeur,) the cast-iron chest enclosing the slides. Sp. caja de válvulas.

Valve-gearing, (Fr. armature du tiroir). Sp. armadura de las válvulas.

Velocity, (Fr. vitesse). Sp. velocidad.

Vice-bench, Sp. banco de herrero.

Wales, Sp. cintas de un buque.

Wages, (Fr. gages, salarie). Sp. salario.

Washers are the round pieces of thin iron or brass interposed between the nut of a bolt and the surface upon which it is screwed down. Sp. arandelas.

Waste-steam pipe (the) leads from the *valve-chest* on the top of the boilers, to carry off the steam escaping through the safety-valve. Sp. tubo de desahogar.

Waste-water pipe, see *Discharge pipe*.

Water-gauges, namely, *glass water-gauge*, and the *brass gauge-cocks*, are attached to the front of the boiler for showing the level of the water. Sp. llaves de prueba.

Water-tight, (Fr. etanche d'eau). Sp. á prueba de agua.

Water-wheel, Sp. rueda hidraulica.

Wear, (Fr. usure). Sp. gastado.

Wedge, (Fr. coin). Sp. cuña.

Weigh-shaft, the rocking shaft used in working the slide-valves by the eccentric. Sp. eje oscilante de las válvulas corredizas.

Wheel, Sp. rueda.

Wheel-cutting and dividing machine, Sp. máquina de cortar y graduar ruedas.

Whistle, Sp. pito de vapor.

White-lead, Sp. alballalde.

Worm-wheel, a wheel with teeth, formed to fit into the spiral spaces of a screw, so that the wheel may be turned by the screw, or *vice versd*. Sp. rueda de tuerca.

GLOSSARY OF TERMS

CONNECTED WITH

MARINE ENGINES AND BOILERS,

IN

SPANISH, FRENCH, AND ENGLISH.

SPANISH.	FRENCH.	ENGLISH.
A prueba de vapor	étanche de vapeur	steam-tight
Abanico		fan
Abatimiento de un buque		lee-way
Ábra de dientes		pitch of a wheel
Aceite	huile	oil
Aceite de linaza		linseed oil
Acero	acier	steel
Aguas muertas	eau morte	still or dead water
Alballalde		white-lead
Almohadilla		buffer
Anillo; centro; dado		bush
Anillo del empaquetado de un émbolo		junk ring
Apaleador		coal-trimmer
Aparato; maquinaria		gearing
Aparato alimenticio	l'appareil alimentaire	feeding apparatus
Aparato de la expansion	l'encliquetage pour l'expansion	expansion gear
Aparato motor		driving apparatus
Aparato para consumir el humo		smoke-burning apparatus
Aparato para hechar para atras la máquina		reversing gear
Arandelas		washers
Arbol de barrenar		boring bar
Ariete de una bomba		pump-ram

SPANISH.	FRENCH.	ENGLISH.
Ariete hidraulico		hydraulic ram
Armadura de las válvulas	armature du tiroir	valve-gearing
Armazon	châssis, cadre	stand or frame of the engine
Arrizar las paletas		reefing the paddles
Asiento de una válvula	siège de la soupape	seat of the valve
Atizador, sable	fourgon, tisonnier	slice (for clearing the air spaces between the bars of a furnace)
Atizar		firing up
Avance de la válvula corrediza	avance du tiroir	lead of the slide-valve
Avance de una válvula corrediza, en el lado del vapor, ó de la entrada		cover or lap of the slide-valve on the steam side
Avance del ciqueñal	avance de la manivelle	lead of the crank
Avance de un tornillo		pitch of a screw
Avance en el lado de vacio, ó de salida		cover or lap on the exhausting side of the piston
Balancines	balanciers	side-levers
Balde		bucket
Banco de herrero		vice-bench
Baos	travers	beams of a vessel
Baos de la máquina		engine-beams
Barómetro	baromètre	barometer or vacuum-gauge
Barra de coneccion	bielle de la manivelle	connecting rod
Barras de la bomba neumática		back-links
Batalla de una bomba		stroke of a pump
Boca ó puerta de la caldera	trou d'homme	man-hole
Bocina del codaste por donde pasa el eje del tornillo		bush of the stern-post
Bomba alimenticia		feed-pump
Bomba aspirante	pompe aspirante	sucking pump
Bomba de aire	la pompe à l'air	air-pump
Bomba de doble accion		double-acting pump
Bomba de fuerza ó de impulsión	pompes foulantes	forcing pumps
Bomba de incendios		fire-engine
Bomba de mano	pompe à bras	hand-pump
Bomba neumática	la pompe à l'air	air-pump
Bombas de purgar	pompes de saumure	brine-pumps, bilge-pumps
Broca		drill
Bronce	bronze	brass, gun-metal
Buque de vapor	bateau à vapeur, pyroscaph	steam boat
Caballo de vapor	puissance en cheval, force de cheval	horse-power

SPANISH.	FRENCH.	ENGLISH.
Cabezada de un buque	plongement	pitching of a vessel
Cabezál de la barra del émbolo		cap of the piston-rod
Cabezál de un torno		head stock
Cabria		shears
Cagera		mortise
Cageta para empaquetar	garniture d'étoupe	gasket
Cairel		shelf
Caja de aire	la chemise	air casing
Caja de empaquetado	boîte à étouffe, le collet	stuffing-box
Caja de humo	boîte à fumée	smoke-box
Caja de las válvulas corredizas	boîte des tiroirs	slide casing or jacket
Caja de una bomba	corps d'une pompe	barrel of a pump
Caja de válvulas	boîte du tiroir, boîte à vapeur	valve-casing
Caja de vapor	reservoir pour la vapeur	steam-chest
Calado	immersion	draught of water
Caldera de baja ó alta presión	chaudière à basse pression, à haute pression	low-pressure or high-pressure boiler
Calderas tubulares		tubular boilers
Calor	chaleur	heat, heating power
Calor latente	chaleur latente	latent heat
Calor sensible		sensible heat
Cama		bed
Cangilon de rueda hidraulica		bucket
Carbon de piedra; carboneras	les houilles, charbon de terre; soutes à charbon	coals; coal-bunkers
Casco de un buque	coque d'un bateau	hull or shell of a boat
Casco de una caldera		shell of a boiler
Cemento	ciment, mastic	cement
Ceniceros	cendriers	ash-pits
Cenizas	scories	clinkers
Centro	moyen	nave of a wheel; bush
Centro de los balancines	goujon central	main centre
Centro de las ruedas de un vapor	renflement central des roues à aubes	centre boss of the paddle-wheels
Cepillo de ciqueñal		crank planing machine
Cepillo mecanico		planing machine
Cepo	contre-clavette	gib, or fixed iron wedge
Chapa de hierro	tôle, fer en feuilles	sheet iron
Chaqueta	la chemise	air casing
Chaveta	clavette	cutter or wedge-key
Chavetas	clef	key
Chavetas abiertas		split pins
Chimenea	cheminée	chimney
Chimenea de anteojo		telescope funnel
Choque		chuck

SPANISH.	FRENCH.	ENGLISH.
Chumacera		bracket pedestal or plummer-block
Chumacera del costado		inside bearings of paddle-shaft
Chumacera ó pedestal del ege		pedestal or plummer-block
Chumaceras de afuera		outside bearings to paddle-shaft
Chupadores	tuyaux à succion, suçoirs	suction pipes
Cincel	ciseau, burin	chisel
Cintas de un buque		wales
Ciqueñal	manivelle, coude	crank
Circulo primitivo ó de contacto de una rueda dentada		pitch circles
Clara del émbolo		clearance of the piston
Codillos		elbows
Coginete		buffer
Colado	coulé	cast
Collar		collar-plate
Collarin	collier	collar of a shaft
Collarin de la barra del émbolo		gland, the collar which encircles the piston and air-pump rod, &c.
Columna vertical de agua		head of water
Combustible	combustible	fuel
Compas curbo		callipers
Condensador	condenseur	condenser
Consumo de combustible	consomption de combustible	consumption of fuel
Contrapeso		balance-weight
Contrapeso de la escéntrica		back-balance of eccentric
Contrapeso de las válvulas correctizas		back-balance of slide-valves
Copas de lubricar		grease-cock
Corona de barrenar		boring head
Correa		strap
Corta hierro; corta frio	ciseau, burin	chisel, cold-chisel
Cortar el vapor	la détente	cutting off the steam
Cruceta	traverse, tête croissée	cross-head
Cruceta de la barra de coneccion		cross-tail
Cuadrado	quarré	square
Cuadrante de las válvulas correctizas		link motion
Cubeta		bucket
Cubierta	pont	deck
Cuchillas para la corona de barrenar ú otras		cutters
Cuello	coussinet d'une arbre	neck bearing or journal
Cuello de un ege	coussinet d'un arbre	neck of a shaft
Cuero	cuir	leather
Cuerpo de una bomba	corps d'une pompe	barrel of a pump

SPANISH.	FRENCH.	ENGLISH.
Cuña	coin, clavette	wedge, cutter or wedge-key
Cuñas ó pernetes de los estribos		stay wedges
Curvas de hierro	équerres en fer	knees of iron
Dado de una roldana		bush
Dados. <i>See</i> Machos		
Depósito	sédiment	scale, incrustation
Depósito de agua caliente	reservoir à l'eau chaude, la citerne	hot water well
Depósito de vapor	espace pour la vapeur	steam room
Desconectar las ruedas ó el tornillo		disengaging or disconnecting the paddles or screw from the engines
Desplazamiento		displacement
Destornilladores		spanners (keys for screwing up nuts)
Diametro de las ruedas de un vapor		effective diameter of a paddle-wheel
Diario de máquina		engine-room log
Diente		tooth
Dinamómetro		dynamometer
Disminucion de mayor á menor		taper
Distancia de centro á centro de dientes medida en el circulo primitivo ó de contacto de una rueda		pitch of a wheel
Dotacion	l'équipage d'un vaisseau	crew of a vessel
Durmientes de la máquina	poutres de fondement, traverses	engine-bearers or sleepers
Durmientes de la caldera		bedding of a boiler
Ege	arbre ; axe, verge	shaft, spindle
Ege intermedio		intermediate shaft
Ege oscilante de las válvulas corredizas		weigh-shaft
Embolo de la bomba neumática		air-pump bucket
Embolo cilindrico que batalla en el empaquetado de la regola de una bomba de fuerza		pump-ram
Embolo sin válvulas de una bomba	plongeur	plunger
Empaquetado del émbolo, &c.	garniture	packing for the piston, slide-valves, &c.
Empaquetado metálico		metallic packing
Emparradillo	grille du foyer	fire-grate
Empernado	boulon, boulonné	bolt, bolted
Empuge del tornillo		thrust of the screw
Enciqueñado	coudé	cranked

SPANISH.	FRENCH.	ENGLISH.
Entabladura		entablature
Escéntrica	l'excentrique	eccentric
Escopleado	assemblé à mortaise	mortised
Escopleadura		mortise
Escoplo mecánico		slotting machine
Escorias	scories	clinkers
Eslora de un buque		length of a ship
Esperimento	expérience	experiment
Espiga	axe, verge	spindle
Estampa		snap
Estela	eau mort	dead-water
Estivar	charger des marchandises	to stow goods
Estopa	étoupe	hemp
Estrepada	effort	strain
Estrobo de la barra de coneccion		connecting-rod strap
Estrobo de una barra		strap
Flus de reunion		up-take. (See 'Up-take' in English Glossary.)
Fluses	conduits	flues
Fogoneros	chauffeurs	fire-men or stokers
Fomentar las calderas		priming or foaming of the boilers
Fornalla	le foyer	furnace, fire-box
Forrar de fieltro		felted
Forrar tubos ó calderas		clothing the steam-pipes, boilers, &c.
Forro del cilindro		laggings for the cylinder, &c.
Franja de una rueda		flange of a wheel
Friccion	frottement	friction
Fuerza calorifica	puissance calorifique	heating power
Fundido	coulé	cast
Garrote de tarrajar		tap-wrenches
Gastado	usure	wear
Gato		screw tack
Gavarra	gabarre	lighter or barge
Golpe de una bomba		stroke of a pump
Golpe del émbolo	course du piston	stroke of the piston
Gonces		hinges
Grifo	robinet	cock
Grifo de dos vias	robinet à deux eaux	two-way cock
Guardas de tuercas		guards
Guias	glissoirs	guides
Gusanillo	filet d'une vis	thread of a screw

SPANISH.	FRENCH.	ENGLISH.
Hacer agua		to leak
Hechar atras los fuegos		banking up the fires
Hechar fuera; purgar		blowing off
Henchimiento	renflement	boss
Herrero	forgeron	smith
Hidrómetros		glass water-gauges
Hierro colado	fonte	cast iron
Hierro de ángulo	cornière	angle-iron
Hilo		thread
Horno	le foyer	furnace, fire-box
Horno de reberbero		blast-furnace, air-furnace, reverberatory furnace
Horquilla	fourche	fork
Immersion de las paletas		dip of the wheels
Incrustacion	sédiment	incrustation
Indicador	indicateur	indicator
Inyeccion	injection	injection
Inyeccion de la sentina		bilge injection
Junta de expansion		expansion or Fawcett joint
Junta de un ege		coupling of a shaft
Juntas	charnières, articulations	joints
Juntas de cemento		rust joints
Lanchon	gábarre	lighter or barge
Lastre	sable	ballast
Ligazones	tirans	ribs
Limaduras de hierro	limaille	iron filings
Limas	limes	files
Linea recta	ligne droite	straight line
Llave	clef, robinet	key, cock
Llave alimenticia		feed-cock
Llave de dos vias	robinet à deux eaux	two-way cock
Llave de hechar fuera el agua del cilindro		pet-cock or test-cock
Llaves de destornillar; destornilladores		spanners (keys for screwing up nuts)
Llaves de prueba	robinets d'épreuve	gauge-cocks, water-gauges
Llaves de prueba para medir el agua de la caldera		water-gauges
Llaves de purgar		blow-off cocks and pipes
Lona		canvas

SPANISH.	FRENCH.	ENGLISH.
Longitud del golpe	longueur du coup ou de la course	length of stroke
Lubricadores	godets, ou boîtes à huile	lubricators or oil-cups
Lubricadores de sifon		syphon oil-cups
Luchadero	coussinet	journal, the neck or bearing part of a shaft
Luchadero de un ege	coussinet d'une arbre	neck bearing or journal
Luz del émbolo		clearance of the piston
Machina; cabria		shears
Macho de tarrajar y concluir las tuercas		master tap
Machos y dados (hembras) de tarrajar		taps and dies
Macilla		putty
Malletes de la rueda		spring beams
Mamparos	cloisons	bulk-heads
Manga de un buque		breadth of a ship
Mango	manette	handle
Maniguetas de taladro		drill braces
Manómetro	manomètre de verre mercurial, manomètre pour la vapeur	steam or mercurial gauge
Manquera		fire-hose
Manubrio	manivelle, coude	crank
Máquina alimenticia	machine alimentaire	auxiliary, donkey, or feeding engine
Máquina atmosférica	machine à vapeur atmospherique	atmospheric or single-acting engine
Máquinas de alta presion	machines à haute pression	non-condensing or high-pressure engines
Máquina de babor		larboard engine
Máquinas de balancin	machines à balanciers	beam or side-lever engines
Máquina de cepillar		planing machine
Máquina de condensacion	machine à condensation	condensing engine
Máquina de cortar y graduar ruedas		wheel-cutting and dividing machine
Máquina de doblar planchas		plate-bending machine
Máquina de doble accion	machine à double action	double-acting engine
Máquina de doble cilindro		double-cylinder engine
Máquina de escoplear		slotting machine
Máquina de estribor		starboard engine
Máquina de maleta		trunk engine
Máquina de recortar		shaping machine
Máquina de recortar tuercas y ca- bezas de tornillos		bolt head and nut shaping machine
Máquina de remachar		riveting machine
Máquina de taladrar y barrenar		drilling and boring machine
Máquina de tarrajar		screwing machine
Máquina de vapor	machine à vapeur	steam engine

SPANISH.	FRENCH.	ENGLISH.
Máquinas de vapor de acción directa		direct-acting engines
Máquinas oscilatorias	machines aux cylindres oscillantes	oscillating engines
Máquinaria		machinery, gearing
Máquinista	machiniste, mecanicien	engineer, engine tender
Martillos	marteaux	hammers
Medida		standard
Mesa de una herramienta mecánica		table
Metal de Babbit para coginetes ó centros		Babbit's patent bushes
Metal de Muntz		Muntz's metal
Metro	mètre	metre
Miembros	membrures d'un vaisseau	frames of a vessel
Milla nautica		geographical or nautical mile
Minio		red-lead
Mortaja	encoche	notch
Mortero de la bomba neumática		air-pump bucket
Movimiento alternado	alternatif	reciprocating
Movimiento paralelógramo	le parallélogram	parallel motion
Muelles	ressorts	springs
Muestra del indicador		diagram of indicator
Muñon	goujon	gudgeon
Muñon de un eje	coussinet d'une arbre	neck bearing or journal
Muñonera		bracket pedestal or plummer-block
Muñones		trunnions
Nivel	niveau	level
Norma		standard
Nudo		knot, or geographical or nautical mile
Ojo de un ciqueñal	encoche, œil	eye of a crank, &c.
Orilla, franja	rebord	flange
Pala	pelle	shovel
Palanca	levier	lever
Palanca de hechar á andar la máquina	encliquetage régulateur	starting gear
Palanquillas		links
Paletas	les aubes ; les rais des roues	paddle-boards or float-boards ; paddle-arms
Parrillas	barras du foyer	fire-bars
Parte que roza	partie frottante	rubbing part
Pasamano		hand-rail

SPANISH.	FRENCH.	ENGLISH.
Peana	plague du fond	sole plate, base plate, or foundation plate
Pedestal del eje		pedestal or plummer-block
Pérdida		slip
Pérdida de las paletas ó del tornillo		slip of the paddle-wheel or screw
Pernete	happe, boulon; goujon	pin; gudgeon
Pernetes de los estribos		stay wedges
Perno	boulon, boulonné	bolt, bolted
Perno del ciqueñal		crank-pin
Pernos de asegurar la máquina		holding-down bolts
Pernos de tornillo	boulons en vis, boulons taraudes	screw-bolts
Perro		a bear, for punching holes
Perro	contre-clavette	gib, or fixed iron wedge
Pescante		crane
Peso de muelle	balance à ressort	spring balance
Pié cuadrado	pied carré	square foot
Piezas de respeto	pièces de réchange	spare gear
Piñon		pinion
Pinzote	axe, verge	spindle
Pito de vapor		whistle
Planchas de hierro, &c.	lames, tolles	plates
Plantilla		template
Polea		pulley
Popa	poupe	stern
Portas de salida	tuyaux de sortie, ou d'émission	eduction or exhaust passages
Portas del cilindro		ports of the cylinder
Puente de una caldera		bridge of a boiler
Puerta de la caldera	trou d'homme	man-hole
Puntal de un buque	hauteur d'un vaisseau	depth of a vessel
Punto de apoyo	support, palier, crapaudine	fulcrum
Punzon		a drift
Punzon y tigera mecánicos		punching and shearing machine
Purgar de aire	purger d'air	blowing through
Quilla		keel
Radio de una curva	rayon de courbe	radius of curvature
Radios del paralelógramo	la bride du parallélogram	radius rods or bars
Ranura	trou, entaille	groove, mortise
Recortador		shaping machine
Redoblon		rivet
Refrigerante		refrigerator
Refuerzo	renflement	boss
Registro de limpieza en las calderas	orifice de nettoyage	mud-hole
Registros de la chimenea ó fornalla	les registres	dampers

SPANISH.	FRENCH.	ENGLISH.
Regola	collier	collar, flange
Regulador	régulateur	governor
Remache		rivet
Remate horquillado		fork-head
Remolcador	pyroscaph remorquant; remorqueur	steam tug; tug or towing boat
Retranca	frein	break or brake
Roce	frottement	friction
Romana de una válvula		lever of a valve
Rosca	filet d'une vis	thread of a screw
Rueda		wheel
Rueda de hechar á andar la máquina	encliquetage régulateur	starting gear
Rueda de linguete		ratchet-wheel
Rueda de tuerca		worm-wheel
Rueda de un vapor	roues à aubes, tambours	paddle-wheels
Rueda dentada ordinaria		spur-wheel
Rueda en angulo de 45°		mitre-wheel
Rueda hidraulica		water-wheel
Rueda motriz ó motora	roue motrice	driving-wheel
Rueda oblicua		bevel-wheel
Rueda voladora, volante		fly-wheel
Ruedas de cambio de un torno		change wheels
Ruedas de Morgan, ó de paletas movibles		feathering paddle-wheels (Morgan's patent)
Ruedas dentadas con madera	roues dentées	cogged wheels
Sable, atizador	fourgon, tisonnier	slice (for clearing the air spaces between the bars of a furnace)
Salario	gages, salaire	wages, salary
Salinómetro	salinomètre	salinometer
Salirse el aqua ó el vapor		to leak
Sebo	suif	tallow
Sedimento	sédiment	scale, incrustation
Sobre quillas	carlingues	keelsons
Soldadura		solders (for joining metals together)
Soplon		counter
Soporte mecánico ó corredizo		slide-rest
Soquete	socle, crapandine	socket
Sosten		stand
Sosten de las parrillas		bearers
Stribos interiores de la caldera		stays
Superficie de calorico ó de fuego		effective heating surface
Tablon		plank

MARINE ENGINES AND BOILERS.

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SPANISH.	FRENCH.	ENGLISH.
Taladro		drill
Taladro mecánico		drilling and boring machine
Tambor		drum
Tambores	tambours	paddle-boxes
Tapa de chumacera		cap
Tapa ó plato del cilindro	couvercle de cylindre	cylinder cover
Tapon	bouchon	plug
Tapon fundible	bondelles fusibles	fusible plugs
Tapones de tubos		tube-plugs
Tarrajá de mano de Whitworth		guide-screw stock
Tarugo	bouchon	plug
Tigeras		shears
Timon	gouvernail, timon ; timonier	rudder, helm ; helmsman
Timonel	timonier	steersman
Tirantes		stays
Tiro de la chimenea	tirage	draught of the chimney
Tonelada	tonne	ton. (See 'Ton' in Engl. Gloss.)
Tope de la válvula de expansion		cam, for expansion
Topes de la escéntrica		stops or snugs of eccentric
Tornillo, tornillado	vis, vissé	screw, screwed
Tornillo alimenticio ó de guía		guide-screw
Tornillos	boulons en vis, boulons taraudés	screw-bolts
Tornillos de rosca de madera		coach-screws
Torno		lathe
Torno cortado		break lathe
Torno mecánico de alimento propio		self-acting lathe
Trabajo medio de una máquina		duty of an engine
Transporte	transportation ; montage	carriage by sea ; carriage by land
Tripulacion	l'équipage d'un vaisseau	crew of a vessel
Tubo		pipe
Tubo alimenticio		feed-pipe
Tubo de aire		air-pipe
Tubo de avivar el fuego		blast-pipe
Tubo de desahogar		waste-steam pipe
Tubo de una bomba	corps d'une pompe	barrel of a pump
Tubo y válvula de descarga	tuyau et soupape de décharge, ou de sortie	discharge, delivery, or waste-water pipe and valve
Tubos de purgar la caldera		blow-off cocks and pipes
Tubos de salida	tuyaux de sortie, ou d'émission	eduction or exhaust passages
Tuerca	ecrou	nut, thread
Válvula de arandela		clack-valve
Válvula de descarga		discharge or delivery valve
Válvula de disco		disc-valve
Válvula de escape		escape-valve

SPANISH.	FRENCH.	ENGLISH.
Válvula de paso	soupape regulateur	throttle-valve
Válvula de pie	clapet de fond	foot-valve
Válvula de purgar de aire	soupape à purger d'air	blow-through valve
Válvula de purgar de agua el condensador	soupape reniflante	snifting valve
Válvula esferica		ball-valve
Válvulas	valvules, soupapes, clapets, tiroirs	valves
Válvulas atmosféricas	soupapes de sûreté intérieures	reverse or vacuum valves
Válvulas con el ege enroscado		Kingston's valves
Válvulas cónicas		cup-valves
Válvulas corredizas	tiroirs, soupapes à tiroir	slide-valves
Válvulas de comunicacion		stop-valves or communication-valves
Válvulas de escape de la bomba alimenticia		escape-valves
Válvulas de escape del cilindro	soupapes d'échappement	escape or priming valves
Válvulas de seguridad	soupapes de sûreté	safety-valves
Válvulas dobles ó de equilibrio		equilibrium, Cornish, or double-beat valves
Válvulas resbaladizas	tiroirs, soupapes à tiroir	slide-valves
Vapor de alta presion	vapeur à haute pression	high-pressure steam
Velocidad	vitesse	speed, velocity
Viage de las válvulas	course du tiroir	travel of the valves
Viage de la válvula corrediza		slide-valve travel
Vientos de la chimenea		shrouds for the funnel
Virolas	viroles	ferrules
Visagras		hinges
Vitolas		gauges
Volante, rueda voladora		fly-wheel
Yanta (la) de las ruedas de los locomotores		tire of the wheels
Yanta de una rueda		flange of a wheel
Yunque	masse	anvil

T. G. QUESADA, Capt. Royal Spanish Navy.

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